Effect Of Packing Density On Compressive Strength Of High Strength Concrete

Owus M. Ibearugbulem, J. C. Ezeh and Johnson Ibezim

Abstract: The collapse of civil engineering constructions has resulted in injuries, loss of lives, and investments which have been largely attributed to the quality of concrete ingredients used. The need to achieve certain properties suitable for a particular construction and the need to reduce cost in construction projects and achieve optimal results cannot be overemphasized. The study is based on the effect of packing density on the compressive strength of high-strength concrete with the application of metakaolin and conplast SP430 superplasticizer. To achieve this, five different combinations of coarse and fine aggregates for different packing densities were considered, with four different percentages of replacement of cement with Metakaolin (0%, 5%, 10%, and 15%). Therefore, based on the results obtained, it can be clearly stated that the packing density of concrete ingredients should be considered to improve the compressive strength and slump value of high-strength concrete.

Index Terms: Aggregates, compressive strength, concrete, high strength concrete, metakaolin, packing densities, slump, superplasticizer.

1 INTRODUCTION

The quality of constituent materials used in the preparation of concrete contributes immensely to the development of the physical and strength properties of the resultant concrete. In concrete preparation, water, cement, fine aggregates, coarse aggregates and admixtures used should be free from the harmful substance that may adversely affect the properties of the hardened concrete. Varela, Quito & Piaza (2015) revealed that concrete is used in many ways and is subjected to a variety of loading conditions; hence, different types of stresses are developed. They further revealed that very often the dominant stress is compressive in nature since the material has long been known to exhibit its best strength characteristics when subjected to compressive loading. According to Abah Ndu-buba & Ikpe (2018) concrete is widely used material, the best in the construction industries, which made it very popular and versatile. Concrete is a composite inert material comprising of a binder course such as cement, mineral filler (body) or aggregates categorized as, fine (sand) and coarse (gravel or crushed stone) aggregates and water. Generally, concrete is classified as dense and lightweight. Lightweight concrete can be described as those weighing less than 1920 kg/m^3. Lightweight concrete includes aerated, lightweight aggregates and non-fines concrete; while dense concrete is the popular type for reinforced concrete works with an average density of about 2400 kg/m^3. Abah Ndu-buba & Ikpe (2018) further explained that concrete is a very variable material having a wide range of strengths and stress-strain curves, it is any product or mass made by the use of cementing medium, and it is a composite material (Abah Ndu-buba & Ikpe, 2018). It is, therefore, possible to mention that concrete comprises mixing cement, aggregates, and sometimes admixtures in appropriate proportions within the presence of water. The mixture, which undergoes reaction, forms a paste and when allowed to cure becomes solid stone.

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The compositions are natural materials usually extracted from the immediate environment (Abah Ndu-buba & Ikpe, 2018). The method and material used in the preparation of concrete determine the strength of the concrete. Cement, water, sand, and coarse aggregate are proportioned and mixed to produce concrete suited to a particular work. The packing density of aggregates is the ratio of the packing mass of combined aggregates to the bulk volume of the combined aggregates. James Idala (2019) thus states that concrete is viewed largely as been made up of particles of various sizes, its properties are greatly affected by the packing density of its solid ingredients, he further explained that researches on the packing density of concrete ingredients, i.e. Aggregate (fine and coarse) particles, and cementitious (Portland cement) materials can help to improve the performance of concrete in its fresh and hardened state. And that excess paste lubricates the concrete mix. Therefore, at the same paste volume, a higher packing density of the aggregate would increase the amount of excess paste and lead to higher workability. In the other words, at the same workability requirement, a higher packing density of the aggregate would allow the use of a smaller paste volume to increase dimensional stability and reduce cement consumption, cost of production and the carbon footprint of the concrete (James Idala 2019). Ajamu, Ige & Oloyede, (2005) stated that aggregates take about three-quarters of the volume of concrete with the coarse aggregates taking between 50 and 60% of the concrete mix depending on the mix proportion used. Ibearugbulem & Igwilo (2019) states that aggregates comprise as much as 60% to 80% of a typical concrete mix. So they must be properly selected to be durable, blended for optimum efficiency, and properly controlled to produce consistent concrete strength, workability, and durability (Ibearugbulem & Igwilo, 2019). The subject of optimizing the concrete composition by selecting the proper amounts of varied particles has already aroused interest for over a century. To optimize the particle packing density of concrete, the particles should be selected to fill the voids between large particles with smaller particles so as to get a dense and stiff particle structure (Raj, Patil & Bhattacharjee, 2014). Madani, Rostami, Norouzifar & et al (2017), said the optimization of aggregate proportioning would be a major factor to enhance the packing density of concrete In other words, the particles should be chosen in the way that the smaller ones could just fill the voids between larger particles. Aggregate packing density and gradation have important effects on the concrete characteristics where aggregates with higher packing density have less void content and, as a result, need lower cement paste to refill empty spaces. This make the mixtures more economical (Madani, Rostami, Norouzifar & et al 2017), and increasing the packing density is crucial for producing composite materials like ceramics and concrete. According to Nimodiya & Patel (2018) good packing density does not only results in better workable concrete but also give better strength with lesser paste volume and the effect of Packing density will be naturally more if the volume of aggregate is more in concrete mix or in other words if the volume of paste is less. So, for a lower grade of concrete in which paste required is less, if one uses fine and coarse aggregate combination with higher packing, it is possible to achieve good fresh and hardened properties even with less paste (Nimodiya & Patel, 2018). The main objective of using particle packing density is to obtain the dense packing of aggregate particles and to minimize the cement requirement (Kore, 2018). Therefore, this study is based on investigating the effect of packing density on compressive strength of high-performance concrete with the application of metakaolin and conplast SP430 superplasticizer.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

The Materials used are coarse aggregate, fine aggregate, Portland cement, metakaolin and Conplast SP430 Super plasticizing admixture.

2.1.1 Metakaolin

The clay used was quarry from Obuburu community in Ogba/Egbema/Ndoni Local Government Area, Rivers State, Nigeria. It was calcined to the required temperature, the calcined clay (Metakaolin) was tested in the laboratory and the results are shown Table 1. The metakaolin used was considered in four different percentages in-relation to cement content. They are 0%, 5% 10%, and 15% of metakaolin in-relation to cement content. It was done for each packing of coarse and fine aggregate as shown in Table 9.

Table 1: Properties of Metakaolin

Properties of Metakaolin	Values
Specific gravity	2.240
Non-compacted Bulk density	756.25 kg/m^3
Fineness modulus	1.69

2.1.2 Aggregates

The fine aggregate was obtained from Federal University of Technology Owerri (FUTO) Imo state mining field (Otamiri), the fine aggregate was tested in the laboratory and the results are shown Table 2. The coarse aggregate, which is from crushed granite rock with a maximum particle size of 10mm was obtained from local quarry/market and was used as coarse aggregate. The properties were shown in Table 2 below.

Table 2: Properties of fine aggregate

Properties of fine aggregate	Values
Specific gravity	2.593
Bulk density	1727.29 kg/m^3
Fineness modulus	2.31
Zone	11
Water absorption	1.59%

Table 3: Properties of coarse aggregate

Properties of coarse aggregate	Values
Specific gravity	2.532
Bulk density	1500.52 kg/m^3
Fineness modulus	5.54
Water absorption	4.38%

2.1.3 Ordinary Portland cement

Ordinary Portland cement (OPC) was used as the binding agent/material in the experiment. It is ordinary Portland cement of grade 42.5 (BUA Cement) and it complies with (NIS 444-1, 2003).

2.1.4 Superplassticizer

Conplast SP430 was used as super plasticizer for the experiment, which complies with the requirements of the following standards: BS 5075 Part 3, BS:EN934-2 and with ASTM C 494 as Type A and Type F. The dosage used for this experiment was 2.00 litres/100 kg of cementitious material. Some of the properties are as shown in Table 4.

Table 4: Properties of liquid conplast SP 430 superplasticizer

S/No	Description	Properties
1	Appearance	Brown liquid
2	Specific gravity	Typically 1.20 at 20°C
3	Chloride content	Nil
4	Air Entrainment	Typically less than 2% additional air is entrained at normal dosages.
5	Alkali content	Typically less than 72.0g. Na_2O equivalent/litre of admixture. A fact sheet on this subject is available.
6	Solid content	40%
7	Operating temperature	10°C to 40°C

Source: Fosroc idea construction chemicals co.(2007), Thangaraj & Thenmozhi (2012).

2.2 Methods

2.2.1 Packing Density of different combinations of fine and coarse aggregates

Packing density of fine and coarse aggregates used was determined experimentally using cylindrical container. The proportions/Packing of fine aggregate and coarse aggregate used were determined as follows:

The range of coarse aggregate proportion is

$$0.45 \leq x_c \leq 0.65 \quad (1)$$

The range of fine aggregate proportion is

$$0.35 \leq x_f \leq 0.55 \quad (2)$$

Where:

$$x_c + x_f = 1 \quad (3)$$

The five combinations of packing density used in the experiment are shown in Table 5. Table 6 shows the volume of void in one cubic meter of aggregate packing. The unit relative surface areas (URS) of the Wet (SSD) bulk of coarse aggregate and wet (SSD) bulk of fine aggregate are 2.913 and 168.754 respectively, therefore the total relative surface area and the thickness of paste needed to cover the grains of the aggregates are determine as shown in Table 7 and Table 8 respectively.

Table 2.5: Combinations of packing density for fine and coarse aggregate

S/n	Packing code	Coarse aggregate portion, x_c (%)	Fine aggregate portion, x_f(%)
1	J	0.65	0.35
2	K	0.60	0.40
3	L	0.55	0.45
4	M	0.50	0.50
5	N	0.45	0.55

Table 2.6: Volume of void in one cubic meter of aggregate packing

S/n	Coarse aggregate portion, x_c(%)	Fine aggregate portion, x_f(%)	(PBD) Packing Bulk Density Measured (kg/m^3)	Combined specific gravity, G = (Gg *x_c + Gs*x_f)/(x_c + x_f)	Volume of void = (G*1000 - PBD)/ (G*1000)
1	0.65	0.35	1822.89	2.553	0.286
2	0.60	0.40	1832.71	2.556	0.283
3	0.55	0.45	1824.09	2.559	0.287
4	0.50	0.50	1774.14	2.563	0.308
5	0.45	0.55	1763.91	2.566	0.312

Table 7: URS for granite is 2.913 and URS for sand is 168.754.

S/n	Coarse aggregate portion, x_c m^3	Fine aggregate portion, x_f m^3	Relative surface area of gravel $= x_c \times$ URS	Relative surface area of Sand $= x_f \times$ URS	Total relative Surface area
1	0.65	0.35	1.89345	59.0639	60.95735
2	0.60	0.40	1.7478	67.5016	69.2494
3	0.55	0.45	1.60215	75.9393	77.54145
4	0.50	0.50	1.4565	84.377	85.8335
5	0.45	0.55	1.31085	92.8147	94.12555

Table 8: Thickness of paste needed to cover the grains of the aggregate

S/n	Coarse aggregate portion, x_c m^3	Fine aggregate portion, x_f m^3	Volume of void $= \frac{G \times 1000 - PBD}{G \times 1000}$	Total relative Surface area	Relative thickness of paste covering of aggregates $= vol./area \times 1000$
1	0.65	0.35	0.286	60.957	4.693100996
2	0.60	0.40	0.283	69.249	4.087977658
3	0.55	0.45	0.287	77.542	3.705269891
4	0.50	0.50	0.308	85.833	3.584299836
5	0.45	0.55	0.312	94.126	3.319640629

2.2.2 Mix Proportions, Workability Test and Compressive Strength Test of Concrete

The mix proportions and mix quantities used for the various packing densities were design using BS 5328: Parts 1, 2, 3 & 4, 1997, with concrete grade of C50. The target compressive strength is 50N/mm^2 at 28 days. Minimum cement content is 400 kg/m^3, adjusted water cement ratio is 0.4 and normal weight aggregate of 10 mm nominal size as shown on Table 9. A Total of 20 mixes were prepared, with 180 cubes, which were tested on different crushing ages as 28 days, 56 days and 91 days respectively. It was prepared with constant water content and Super plasticizer. Slump test of the concrete was used to determine concrete workability. This was carried out in accordance to BS EN 12350-2The compressive strength test was conducted on cubes of size 150mm x 150mm x 150mm. The results obtained for each of the crushing ages are shown in Table 11 for 28 days, 56 days and 91 days.

Table 9: Mix design ratios using packing density method

S/n	Packing code	Water kg	Super plasticizer (kg)	Cement (kg)	Metakaolin (kg)	fine aggregate (kg)	Coarse aggregate (kg)
1	J01	0.38	0.0228	1	0	1.6177	2.9337
2	K02	0.38	0.0228	1	0	1.8489	2.708
3	L03	0.38	0.0228	1	0	2.08	2.4824
4	M04	0.38	0.0228	1	0	2.3111	2.2567
5	N05	0.38	0.0228	1	0	2.5422	2.031
6	J51	0.38	0.0228	0.95	0.05	1.6119	2.9231
7	K52	0.38	0.0228	0.95	0.05	1.8422	2.6982
8	L53	0.38	0.0228	0.95	0.05	2.0724	2.4734
9	M54	0.38	0.0228	0.95	0.05	2.3027	2.2485
10	N55	0.38	0.0228	0.95	0.05	2.533	2.0237
11	J101	0.38	0.0228	0.9	0.1	1.606	2.9125
12	K102	0.38	0.0228	0.9	0.1	1.8355	2.6884
13	L103	0.38	0.0228	0.9	0.1	2.0649	2.4644
14	M104	0.38	0.0228	0.9	0.1	2.2943	2.2404
15	N105	0.38	0.0228	0.9	0.1	2.5238	2.0163
16	J151	0.38	0.0228	0.85	0.15	1.6002	2.9019
17	K152	0.38	0.0228	0.85	0.15	1.8288	2.6786
18	L153	0.38	0.0228	0.85	0.15	2.0574	2.4554
19	M154	0.38	0.0228	0.85	0.15	2.286	2.2322
20	N155	0.38	0.0228	0.85	0.15	2.5146	2.009

3 RESULTS AND DISCUSSION

The result for the Slump test of the concrete is presented on Table 10. More so, the results for the compressive strength test for 28 days, 56 days and 91 days are shown on Table 11. It was observed that there was no sign of bleeding and segregation in all the mixes. This is because there is no excess of cement paste available they optimally filled up the voids. This situation improves the cohesiveness of the concrete matrix (Nimodiya & Patel 2018) At 28 days age, packing of 0.45 coarse aggregate and 0.55 fine aggregate at 0% metakaolin (N05) has the optimal compressive strength, with strength 58.23N/mm^2, while the concrete with packing of 0.55 coarse aggregate and 0.45 fine aggregate at 0% metakaolin (L03) and 15% metakaolin (L153) have the least compressive strength 47.40 N/mm^2 each. It is also observed that about 90% of the concrete met the targeted strength of 50N/mm^2 at 28 days. For concrete with metakaolin, the optimal compressive strength at 28 days was achieved with the mix of packing of 0.45 coarse aggregate and 0.55 fine aggregate at 10% metakaolin (N105). The compressive strength measured is 54.94N/mm^2. At 56 days, there was significant increase in the compressive strength of the concrete. However, the concrete mith zero metakaolin has the highest compressive strength of 59.55 N/mm^2 and at this age. The concrete mix that has this compressive strength the one with packing of 0.45 coarse aggregate and 0.55 fine aggregate at 0% metakaolin (N05). The concrete that has metakaolin also recorded increase in their compressive strength at the age of 56 days. The optimal compressive strength of 58.71 N/mm^2 was achieved with a mix of packing of 0.45 coarse aggregate and 0.55 fine aggregate at 10% Metakaolin (N105). The least compressive strength at 56 days is 51.63 N/mm^2. This is from a concrete mix with packing of 0.6 coarse aggregate and 0.4 fine aggregate at 15% metakaolin (K152). The concrete prepared with metakaolin shows an increase in compressive strength at 91days over 60 days. The optimal compressive strength recorded was achieved with a mix of packing 0.5 coarse aggregate and 0.5 fine aggregate at 10% metakaolin (M104). The compressive strength for this mix at 91 days of age is 64.93 N/mm^2. It is observed that all the mixes gave concrete with slump up to and more than 100mm. Only 3.33% of the mixes gave concrete whose compressive strength fell below the target strength of 50 N/mm^2. This indicates that more than 96% of the mixes gave concrete with compressive strength above the target compressive strength. The optimum packing of aggregates is obtained when the coarse aggregate, whose nominal size does not exceed 10mm, is packed with the fine aggregate in the ratio of 0.5 : 0.5. This gives the maximum compressive strength at the age of 91 days of 62.43 N/mm^2 and 64.93 N/mm^2 for 5% metakaolin and 10% metakaolin respectively.

Table 10: Slump Values

S/n	Packing code	Slump value (mm)	Water	Super plasticizer	Cement	MK	fine aggregate	Coarse aggregate
1	J01	180	0.38	0.0228	1	0	1.6177	2.9337
2	K02	160	0.38	0.0228	1	0	1.8489	2.708
3	L03	180	0.38	0.0228	1	0	2.08	2.4824
4	M04	170	0.38	0.0228	1	0	2.3111	2.2567
5	N05	180	0.38	0.0228	1	0	2.5422	2.031
6	J51	170	0.38	0.0228	0.95	0.05	1.6119	2.9231
7	K52	140	0.38	0.0228	0.95	0.05	1.8422	2.6982
8	L53	170	0.38	0.0228	0.95	0.05	2.0724	2.4734
9	M54	160	0.38	0.0228	0.95	0.05	2.3027	2.2485
10	N55	170	0.38	0.0228	0.95	0.05	2.533	2.0237
11	J101	140	0.38	0.0228	0.9	0.1	1.606	2.9125
12	K102	115	0.38	0.0228	0.9	0.1	1.8355	2.6884
13	L103	150	0.38	0.0228	0.9	0.1	2.0649	2.4644
14	M104	150	0.38	0.0228	0.9	0.1	2.2943	2.2404
15	N105	160	0.38	0.0228	0.9	0.1	2.5238	2.0163
16	J151	110	0.38	0.0228	0.85	0.15	1.6002	2.9019
17	K152	90	0.38	0.0228	0.85	0.15	1.8288	2.6786
18	L153	125	0.38	0.0228	0.85	0.15	2.0574	2.4554
19	M154	130	0.38	0.0228	0.85	0.15	2.286	2.2322
20	N155	140	0.38	0.0228	0.85	0.15	2.5146	2.009

Table 11: Summary of the compressive strength

Combina-tion	days	Packing code	water	super plasticizer	cement	MK	sand	Granite	Compressive strength (N/mm^2
0.65 granite 0.35 sand	28		0.38	0.0228	1	0	1.618	2.934	53.69
	56	J01	0.38	0.0228	1	0	1.618	2.934	54.87
	91		0.38	0.0228	1	0	1.618	2.934	55.69
0.60 granite 0.40 sand	28		0.38	0.0228	1	0	1.849	2.708	52.43
	56	K02	0.38	0.0228	1	0	1.849	2.708	52.71
	91		0.38	0.0228	1	0	1.849	2.708	53.94
0.55 granite 0.45 sand	28		0.38	0.0228	1	0	2.08	2.482	47.4
	56	L03	0.38	0.0228	1	0	2.08	2.482	57.87
	91		0.38	0.0228	1	0	2.08	2.482	58.18
0.5 granite 0.5 sand	28		0.38	0.0228	1	0	2.311	2.257	56.13
	56	M04	0.38	0.0228	1	0	2.311	2.257	56.85
	91		0.38	0.0228	1	0	2.311	2.257	57.55
0.45 granite 0.55 sand	28		0.38	0.0228	1	0	2.542	2.031	58.23
	56	N05	0.38	0.0228	1	0	2.542	2.031	59.55
	91		0.38	0.0228	1	0	2.542	2.031	57.18
0.65 granite 0.35 sand	28		0.38	0.0228	0.95	0.05	1.612	2.923	52.85
	56	J51	0.38	0.0228	0.95	0.05	1.612	2.923	55.36
	91		0.38	0.0228	0.95	0.05	1.612	2.923	57.87
0.60 granite 0.40 sand	28		0.38	0.0228	0.95	0.05	1.842	2.698	50.75
	56	K52	0.38	0.0228	0.95	0.05	1.842	2.698	55.31
	91		0.38	0.0228	0.95	0.05	1.842	2.698	58.56
0.55 granite 0.45 sand	28		0.38	0.0228	0.95	0.05	2.072	2.473	53.69
	56	L53	0.38	0.0228	0.95	0.05	2.072	2.473	56.2
	91		0.38	0.0228	0.95	0.05	2.072	2.473	58.81
0.5 granite 0.5 sand	28		0.38	0.0228	0.95	0.05	2.303	2.249	47.98
	56	M54	0.38	0.0228	0.95	0.05	2.303	2.249	57.97
	91		0.38	0.0228	0.95	0.05	2.303	2.249	62.43
0.45 granite 0.55 sand	28		0.38	0.0228	0.95	0.05	2.533	2.024	52.85
	56	N55	0.38	0.0228	0.95	0.05	2.533	2.024	53.43
	91		0.38	0.0228	0.95	0.05	2.533	2.024	57.18
0.65 granite 0.35 sand	28		0.38	0.0228	0.9	0.1	1.606	2.912	52.43
	56	J101	0.38	0.0228	0.9	0.1	1.606	2.912	54.89
	91		0.38	0.0228	0.9	0.1	1.606	2.912	56.69
0.60 granite 0.40 sand	28		0.38	0.0228	0.9	0.1	1.835	2.688	54.04
	56	K102	0.38	0.0228	0.9	0.1	1.835	2.688	54.92
	91		0.38	0.0228	0.9	0.1	1.835	2.688	57.87
0.55 granite 0.45 sand	28		0.38	0.0228	0.9	0.1	2.065	2.464	52.43
	56	L103	0.38	0.0228	0.9	0.1	2.065	2.464	54.31
	91		0.38	0.0228	0.9	0.1	2.065	2.464	60.43
0.5 granite 0.5 sand	28		0.38	0.0228	0.9	0.1	2.294	2.24	53.27
	56	M104	0.38	0.0228	0.9	0.1	2.294	2.24	55.1
	91		0.38	0.0228	0.9	0.1	2.294	2.24	64.93
0.45 granite 0.55 sand	28		0.38	0.0228	0.9	0.1	2.524	2.016	54.43
	56	N105	0.38	0.0228	0.9	0.1	2.524	2.016	58.71
	91		0.38	0.0228	0.9	0.1	2.524	2.016	56.56
0.65 granite 0.35 sand	28		0.38	0.0228	0.85	0.15	1.6	2.902	50.15
	56	J151	0.38	0.0228	0.85	0.15	1.6	2.902	51.73
	91		0.38	0.0228	0.85	0.15	1.6	2.902	54.19
0.60 granite 0.40 sand	28		0.38	0.0228	0.85	0.15	1.829	2.679	51.59
	56	K152	0.38	0.0228	0.85	0.15	1.829	2.679	51.63
	91		0.38	0.0228	0.85	0.15	1.829	2.679	54.94
0.55 granite 0.45 sand	28		0.38	0.0228	0.85	0.15	2.057	2.455	47.4
	56	L153	0.38	0.0228	0.85	0.15	2.057	2.455	54.31
	91		0.38	0.0228	0.85	0.15	2.057	2.455	54.57
0.5 granite 0.5 sand	28		0.38	0.0228	0.85	0.15	2.286	2.232	53.27
	56	M154	0.38	0.0228	0.85	0.15	2.286	2.232	53.96
	91		0.38	0.0228	0.85	0.15	2.286	2.232	58.31
0.45 granite 0.55 sand	28		0.38	0.0228	0.85	0.15	2.515	2.009	52.94
	56	N155	0.38	0.0228	0.85	0.15	2.515	2.009	58.08
	91		0.38	0.0228	0.85	0.15	2.515	2.009	59.87

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