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Experimental Study of the Impact of Particle Packing Density Optimization on Strength and Water Absorption Properties of Concrete

Egbe King-James Idala

Department Of Civil Engineering

University Of Agriculture

Makurdi, Benue State

Nigeria

ABSTRACT

The packing characteristics of concrete ingredients (cementitious materials and aggregates) have great influence on the performance of a concrete mix. Herein, a new method, called the wet packing method, developed by H.H.C Wong and A.K.H. Kwan is used to measure and optimize the packing density of ordinary Portland cement and coarse aggregates. It mixes the cementitious materials with water and then measures the apparent density of the resulting mixture at varying water/cementitious materials ratio to characterise the packing behaviour of the cementitious materials. It also measures the aggregate packing in its dry state and its wet state. Using this method, the packing density of pure cement, and blended cementitious materials, single sized 20mm aggregate and blended aggregates under same conditions have been measured. The best three optimizations realized from each category were used to cast concrete cubes in other to determine the impact of the optimization on strength and water absorption. The results show that the best optimized aggregate resulted in a concrete strength increase of 16.63% for 7-days strength and a 6.17% increase in the 28-days strength for grade M20. When OPC was optimized with 20% Silica Fume, an increase in strength of 4.27% (7 days) and 2.78% (28 days) was observed for grade M20 concrete. Water absorption is seen to decrease up to 23.22% as the packing density increased. Based on the results so obtained, it is advocated that packing density optimizations for concrete ingredients should be practised for improved concrete performance.

Key Words: *Packing density, Fly Ash, Silica Fume, Optimization, Ordinary Portland Cement, Aggregates.*

1. INTRODUCTION

Concrete is a composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate.[1]. It can be engineered to satisfy a wide range of performance specification, unlike other building material such as steel, natural rock or wood which generally have to be used as they are. Composite material is made up of various constituents. The properties and characteristics of the composite are functions of the constituent materials' properties as well as the various mix properties of the composite, it is thus necessary to understand these individual constituents as well as the effects of the mix proportions and methods of production [1]. A concrete mixture can thus be viewed as a dry packing of aggregate particles filled up with cementitious paste. Since this matrix is less strong and durable than the natural rock, the basic proportioning strategy is to design the granular mix with the sake of minimum porosity [2], hence the term packing density of particles.

Packing density is defined as the ratio of the solid volume of the particles to the bulk volume occupied by the particles. Since 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 [3], thus research 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. Reference [4] postulated that it is the excess paste (paste in excess of the cement needed to fill the voids between the aggregate particles) that 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 a higher workability. Alternatively, 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.

Following the geometric similarity principle, the packing densities of cementitious material should have a similar effect; an increase in the packing density of the cementitious material should improve the flowability of the paste and/or reduce the water demand. Reference [5] have developed a wet packing density test method to measure the packing density of cementitious material and [3] have also developed wet packing density method for blended fine and coarse aggregate. Thus, this paper intends to showcase the use of the wet packing method to optimize the packing density of Ordinary Portland cement (OPC) using Fly ash, and Silica fume, optimize the packing density of 20mm aggregates by combining it with smaller sized aggregates in a uniform gradation and observe the effect of the best optimized mix on the properties of hardened concrete. The basic mix design of concrete which is the method of providing suitable concrete for engineering purposes has an underlying principle of proportioning various ingredients from charts and tables to achieve the properties desired. However, this basic method has not been able to produce a unique concrete mix which is highly durable and meets strength requirement while minimizing its carbon footprint. This is because the pore space content in normal mixes is high which results from the use of only single sized aggregates [3]. Green concrete which utilizes less cement than conventional mix also requires a different approach [6], and so trade-offs have to be made for the property most desired. In this paper, M20 and M30 normal concrete mix are optimized and the resulting effects on the performance of hardened concrete are studied with respect to strength and durability water absorption.

2. EXPERIMENTATION

2.1 Materials

2.1.1 Fly Ash

Fly ash is a pozzolanas material. It is a finely-divided amorphous alumino-silicate with varying amounts of calcium, which when mixed with Portland cement and water, will react with the calcium hydroxide released by the hydration of Portland cement to produce various calcium-silicate hydrates (C-S-H) and calcium-aluminate hydrates. The fly ash used in this experimentation was obtained locally from Makeri smelting company Jos, Plateau State, Nigeria. Its particle density is 2329 kg/m^3. The composition of major compounds is shown in Table 2.1. According to the chemical composition, the fly ash falls into class “C” of pozzolanas type. The high Loss on Ignition and low silicon dioxide component of the fly ash gives credence to the low early strength in the concrete optimized with fly ash.

Table 2.1: Oxide Composition of Sample Fly Ash

Compound	Percentage (%)
SiO_2	25
Al_2O_3	12
FeO_3	10.27
TiO_2	1.02
MnO	0.12
CaO	35.55
SO_3	5.9
NiO	0.01
Cr_2O_3	0.064
MoO_3	2
PbO	3.7
Others	4.366
Loss on ignition	12.11
Grade	Class C

2.1.2 Silica Fume

The second pozzolanas material used for the optimization experiment was silica fume (amorphous SiO_2). Silica fume is a by-product resulting from the reduction of high quantity quartz with coal in electric arc in the manufacture of silicon or ferrosilicon alloy. The micro silica used was obtained from Igbokoda Jos, Plateau State, Nigeria. Its particle density is 2202 kg/m^3. The composition of major compounds is shown below Table 2.2. From the chemical composition analysis, the silica fume falls into class “F” of pozzolanas type. The high silicon dioxide component of the silica fume is responsible for the high early and late strength in the concrete optimized with silica fume.

Table 2.2: Oxide Composition of Sample Silica Fume (Micro Silica)

Compound	Percentage (%)
SiO_2	95.2
K_2O	0.014
FeO_3	0.803

DOI : 10.31695/IJERAT.2019.

TiO_2	0.0905
MnO	0.012
CaO	1.33
SO_3	0.092
NiO	0.001
Cr_2O_3	0.0454
BiO_3	1.7
Others	0.7031
Loss on ignition	0.04
Type	Uncondensed

2.1.3 Aggregates

The coarse aggregates were obtained from crushed granite rock while the fine aggregate was obtained from the Benue River (washed river sand). Only one size class of fine aggregate with a maximum size of 1.7 mm was used. This size class, named as F1, was obtained by sieving River sand through the 1.18 mm sieve including the portion retained on the 1.7 mm sieve. On the other hand, three size classes of coarse aggregates, named as C1, C2 and C3, were used respectively, as presented in Table 2.3. The solid densities of F1, C1, C2 and C3 under saturated surface dry condition was measured and recorded. All these measurements were carried out in accordance with “Reference [7]”.

Table 2.3: Three Size Classes of Crushed Rock Aggregate and Fine Aggregate

Size Class	**Aggregate mean size (mm)**
C1	10
C2	12.5
C3	20

2.1.4 Ordinary Portland cement

The ordinary Portland cement (OPC) was used in the experiments as the binding material to be optimized. The OPC (Dangote cement) is commonly used cement, and complies with “Reference [8]”.

2.2 Method

The packing density testing and optimization programme was carried out in three phases. First, wet packing density test and optimization for ordinary Portland cement. Second, wet packing density test and blending of coarse aggregate and third, application of optimized concrete ingredients to British mix design.

2.2.1 Wet Packing Density Test and Optimization for Ordinary Portland cement

As postulated by [9] in packing density of cementitious materials; Part-1 measurement using wet packing method; the packing density is not the same as the solid concentration, which varies with the W/C ratio. When the W/C ratio is relatively high, the solid particles are dispersed in the water, resulting in a solid concentration that decreases as the W/C ratio increases. On the other hand, when the W/C ratio is relatively low, the water content is not sufficient to thoroughly mix with the solid particles to form a paste, resulting in a solid concentration that decreases as the W/C ratio decreases. There is an optimum W/C ratio at which maximum solid concentration is achieved. The maximum solid concentration, which occurs when the particles are tightly packed against each other, is taken as the packing density of the granular material. Therefore, to determine the packing density, it is necessary to carry out the wet packing tests at different W/C ratios over a range wide enough to cover the optimum W/C ratio. It should be noted that the W/C ratio by volume is the same as the water ratio ‘u_w’. All W/C ratios referred to hereafter are by volume.

The Procedures of the Test Method

1) The W/CM ratio at which the wet packing test was to be carried out was set. The required quantities of water, cementitious materials and were weighed and each ingredient was dosed into a separate container.

2) Where the cementitious materials consist of several different materials blended together, the materials were pre-mixed dry.

3) All the water was added into the mixing bowl.

4) Half of the cementitious materials was added in bowl and mixed slowly for 2 minutes.

5) The remaining cementitious material was divided into four equal portions. The remaining cementitious materials were then added into the mixing bowl one portion at a time and after each addition, it is mixed slowly for 2 minutes.

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6) The mixture was transferred into a cylindrical mould in three layers and filled to excess. Compaction is applied at this stage (5 blows in 3 layers). The excess is removed with a straight edge and the amount of paste in the mould is weighed.

7) Steps (1) to (6) are repeated at successively lower W/C ratios until the maximum solid concentration, i.e. the packing density, has been found.

From the test results so obtained, the solid concentration may be determined as follows. Let the mass and volume of paste in the mold be 'M' and 'V', respectively. If the cementitious materials consist of different materials denoted by α and β, so forth, the solid volume of the cementitious materials V_c may be worked out from the following equations

$$V_c = \frac{M}{(\rho_w u_w + \rho_\alpha R_\alpha + \rho_\beta R_\beta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots1$$

Where ρ_w is the density of water while ρ_α, ρ_β and ρ_γ are the solid densities of α, β and γ,

And R_α, R_β and R_γ are the volumetric ratios of α, β and γ to the total cementitious materials.

Having obtained V_c the solid concentration (Ø) may be determined as:

$$(\text{Ø}) = \frac{V_c}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots2$$

Shown in Table 2 are parameters measured from the packing density and optimization experiment

Table 2.4: OPC Packing Density and Optimization Test Table

Packing Density And Optimization Table. **Mix; OPC (100%) + Fly Ash (0%) + Silica Fume (0%)** ***Mass Of Cement (g); 200; Density of water*** **($\rho_{w)}$ = 100kg/m^3*****; Volume Of Container (V)(m^3)= 9.6E-5***		
(W/C)	**Volume Of Water ($u_{w)}$ (m^3)**	**Mass Of Mix (g)**
0.0 to 0.7 in steps of 0.1		

The above procedure was repeated and data collected for the following mix ratios;

Table 2.5: Optimization Proportion Employed in OPC Packing Density and Optimization Test.

Optimization with Fly ash	**Optimization with Silica fume**	**Optimization with Fly ash and Silica fume**
OPC (90%) + Fly Ash (10%)	OPC (90%) + Silica Fume (10%)	OPC (80%) + Fly Ash (10%) + Silica Fume (10%)
OPC (80%) + Fly Ash (20%)	OPC (80%) + Silica Fume (20%)	OPC (80%) + Fly Ash (10%) + Silica Fume (20%)
OPC (70%) + Fly Ash (30%)	OPC (70%) + Silica Fume (30%)	OPC (70%) + Fly Ash (20%) + Silica Fume (10%)
		OPC (60%) + Fly Ash (20%) + Silica Fume (20%)

2.2.2 Packing Density Tests and Optimization for Aggregates

The purposes of the testing program is to measure and compare the packing densities of non-blended coarse aggregate and blended coarse aggregate under the similar condition. Three size classes of coarse aggregate, named as C1, C2 and C3, was used for the packing density tests. C1, C2 and C3 are coarse aggregates with mean particle size of 10 mm, 12.5 mm and 20mm aggregates as shown in Table 1. From class C3, a non-blended aggregate sample was taken for packing density tests. Blended aggregate samples were produced by mixing different proportions of coarse aggregate C3, C2 and/or C1. The mix proportions of the blended aggregate samples were defined in terms of their mix ratio. Table 3.3 shows the packing density and optimization table

The Procedures of the Test Method

1) The empty cylinder was weighed

2) The dry bulk density of the coarse aggregate was first measured. The coarse aggregate was poured into the cylinder in three layers and compacted with a tapering rod 25 blows for each layer. The excess is trimmed of by rolling a tapering rod on the surface, it was weighed and recorded dry weight

3) Where the aggregate was composed of various sizes as was the case during optimization, it is mixed dry in the desired proportion and then poured into the cylinder in three layers and compacted with a tapering rod 25 blows for each layer. The excess was trimmed of by rolling a tapering rod on the surface, it was weighed and recorded as dry weight

4) Using measuring cylinder water was poured continuously into the cylinder to fill the pore spaces until it fills the container, the total quantity of water poured is recorded. The mixture was weighed and recorded as wet weight

Solid volume is calculated for wet packing density as follows

$$V_c = \frac{M}{(\rho_w\, u_w + \rho_\alpha\, R_\alpha + \rho_\beta R_\beta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where $\rho_w u_w$ is the density of water while ρ_α, ρ_β and ρ_γ are the solid densities of mixed aggregates α, β and γ.R_α, R_β and R_γ are the volumetric ratios of α, β and γ to the total aggregate mix.

Having obtained V_c the solid concentration (Ø) may be determined as:

$$(\varnothing) = \frac{V_c}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

The parameter '$\rho_w u_w$' is assumed to be equal to zero for dry packing density calculation

Shown in Table 3 are parameters measured from the packing density and optimization experiment

Table 2.6: Packing Density and Optimization Table for Aggregates

<table>
<tr><td colspan="3">Packing Density And Optimization Table.
Mix; C3 (100%) + C2 (0%) + C1 (0%)
<i>Mass Of Aggregate (g);</i>….;<i> Density of water</i> $(\rho_{w)} = 100 kg/m^3$<i>; Volume Of Container (V)</i>(m^3)<i>=</i> <i>2.7E-3</i></td></tr>
<tr><td>Volume of Water added$(u_{w)}$ (m^3)</td><td>Net Weight of Dry Mix (g)</td><td>Mass Of Wet Mix (g)</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Below it is the optimization proportion employed in the packing density and optimization test.

Table 2.6: Optimization proportion employed in the aggregate packing density and optimization test.

Optimization with class C1(10mm)	Optimization with class C2 (20mm)	Optimization with classes C2 and C1(10mm and 12.5mm)
C3 (80%) + C1 (20%)	C3 (80%) + C2 (20%)	C3 (80%) + C2 (10%) + C1 (10%)
C3 (60%) + C1 (40%)	C3 (60%) + C2 (40%)	C3 (40%) + C2 (40%) + C1 (20%)
C3 (40%) + C1 (60%)	C3 (40%) + C2 (60%)	C3 (60%) + C2 (30%) + C1 (10%)

2.2.3 Application of Optimized Concrete Ingredients to British Mix Design

Mix Design 1. (Control) (M20 and M30 According To British Standard)

Concrete mix design of characteristic mean strength of 20MPa and 30MPa was carried out according to the British method of concrete mix selection and the slump, strength (at 7 and 28days), and packing density of aggregate and concrete mix was determined and recorded as control, against which comparison was made.

Mix Design 2. (Control OPC+ Maximum Optimized Aggregate)

Using the required water/cement ratio from the British design method, concrete mixes were made to evaluate the effect of the optimized aggregate on workability and strength.

Mix Design 3. (Maximum Optimized OPC+ Control Aggregate)

Using an average of water/cement ratio corresponding to maximum packing from the optimized OPC, concrete mixes were made to compare the water demand and strength arising from the optimization of OPC i.e. to test the effect of the optimized OPC on workability and strength.

2.2.4 Mix Proportions

The mix proportions and mix quantities for the various mixes required for the test program is shown in Table 2.7

Table 2.7: Concrete Mix Proportions

Mix	**Grade of concrete**	**W/C**	**Optimized aggregate proportion**	**Optimized Cement proportion**	**Mix No**	**Mix Quantities (Kg)**						
						Cementitious Materials				**Coarse Aggregates**		
						OPC	**FA**	**SF**	**Fine Agg**	**C3**	**C2**	**C1**
Control	M20	0.57	-	-	001	7.5	-	-	12.0	26.0	-	-
	M30	0.5	-	-	002	8.5	-	-	11.5	25.5		
Total		12 cubes cast. 3 cubes each for 7days and 28 days										
Control OPC + OPTM. Aggregates	M20	0.57	A	-	003	7.5	-	-	12.0	20.8	5.2	
			B	-	004	7.5	-	-	12.0	15.6	10.4	
			C	-	005	7.5	-	-	12.0	10.4	10.4	5.2
	M30	0.5	A	-	006	8.5	-	-	11.5	20.4	5.1	
			B	-	007	8.5	-	-	11.5	15.3	10.2	
			C	-	008	8.5	-	-	11.5	10.2	10.2	5.1
Total		36 cubes cast. 3 cubes each for 7days and 28 days										
Control Aggregates + OPTM. OPC	M20	0.5	-	D	009	6.75	0.75	-	12.0	26.0	-	-
		0.5	-	E	010	6.00	-	1.50	12.0	26.0	-	-
		0.5	-	F	011	5.25	0.75	1.50	12.0	26.0	-	-
	M30	0.45	-	D	012	7.65	0.85	-	11.5	25.5	-	-
		0.45	-	E	013	6.8	-	1.7	11.5	25.5	-	-
		0.45	-	F	014	5.95	0.85	1.7	11.5	25.5	-	-
Total		36 cubes cast. 3 cubes each for 7days and 28 days										
SUM		**84 cubes**										

***keys**

C3	20mm Aggregate	**OPC**	Ordinary Portland cement	**A**	C3 (80%) + C2 (20%) Coarse Aggregate	**D**	OPC (90%) + FA (10%)
C2	12.5mm Aggregate	**FA**	Fly Ash	**B**	C3 (60%) + C1 (40%) Coarse Aggregate	**E**	OPC (80%) + SF (20%)
C1	10mm Aggregate	**SF**	Silica Fume	**C**	C3 (40%) +C2 (40%) + C1(20%) Coarse Aggregate	**F**	OPC (70%) + FA (10%) +SF (20%)

3. RESULTS AND DISCUSSION

3.1 Wet Packing Density of Ordinary Portland cement

The wet packing behaviour of the cementitious materials may be depicted by plotting the solid concentration of the paste formed against the w/c ratio by volume as shown in Figure 3.1. At a w/c ratio of zero (0), (dry packing) the solid concentration is 0.328 which is low because the air void content is high, as water is added, the solid concentration begins to rise to a maximum of 0.502 at an optimum W/C ratio of 0.4, this indicates that packing density improves with increase in moisture content. Above the optimum W/C ratio, solid concentration begins to decrease because the solid particles are dispersed in water, this leads to a high water void content. In other for the packing density of OPC to increase the air void and water voids need to be filled by particles smaller than the cement particles; this process is referred to as optimization of packing density. This experimental program optimized the packing density of OPC using fly ash and silica fume.

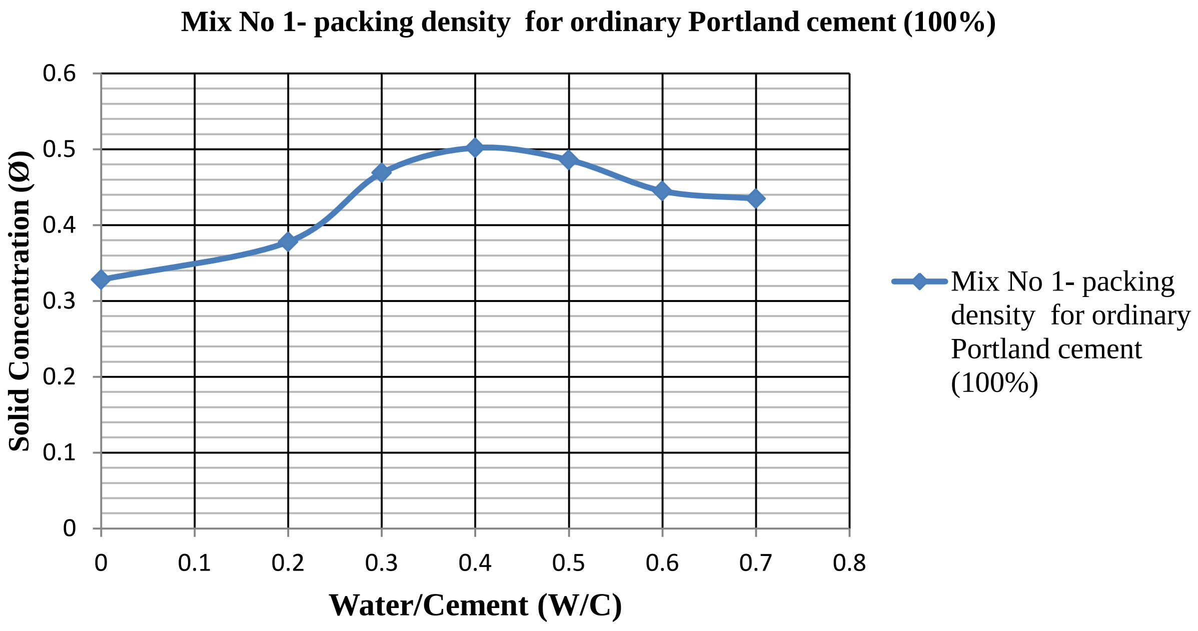

Figure 3.1: Optimization of the Packing Density of OPC with Fly Ash

3.2 Optimization of the Packing Density of OPC with Fly Ash

To evaluate the effects of blending OPC with Fly Ash and determine its degree of improvement of the packing density of OPC, a series of optimization program was carried out. Cementitious materials mixtures have been prepared, containing 90% OPC plus 10% FA, 80% OPC plus 20% FA and 70% OPC plus 30% FA (all percentages are by volume). The test results so obtained are compared to those for pure OPC in Figure 3.1. It is evident from the comparison that blending OPC with Fly Ash could at all W/C ratios significantly increase the solid concentration and thus packing density. The best result was obtained from a mix proportion of 10% OPC replaced by an equal volume of Fly Ash, the maximum packing density increased from 0.502 to 0.556 (9.7% increase) at a W/C of 0.4 as shown in Figure 3.2. The improvement in packing density may be attributed partly to the filling effect of Fly Ash, which reduces the voids volume by filling up the gaps between the OPC particles, and partly to the spherical shape of the Fly Ash particles, which allows better packing to be achieved [5].

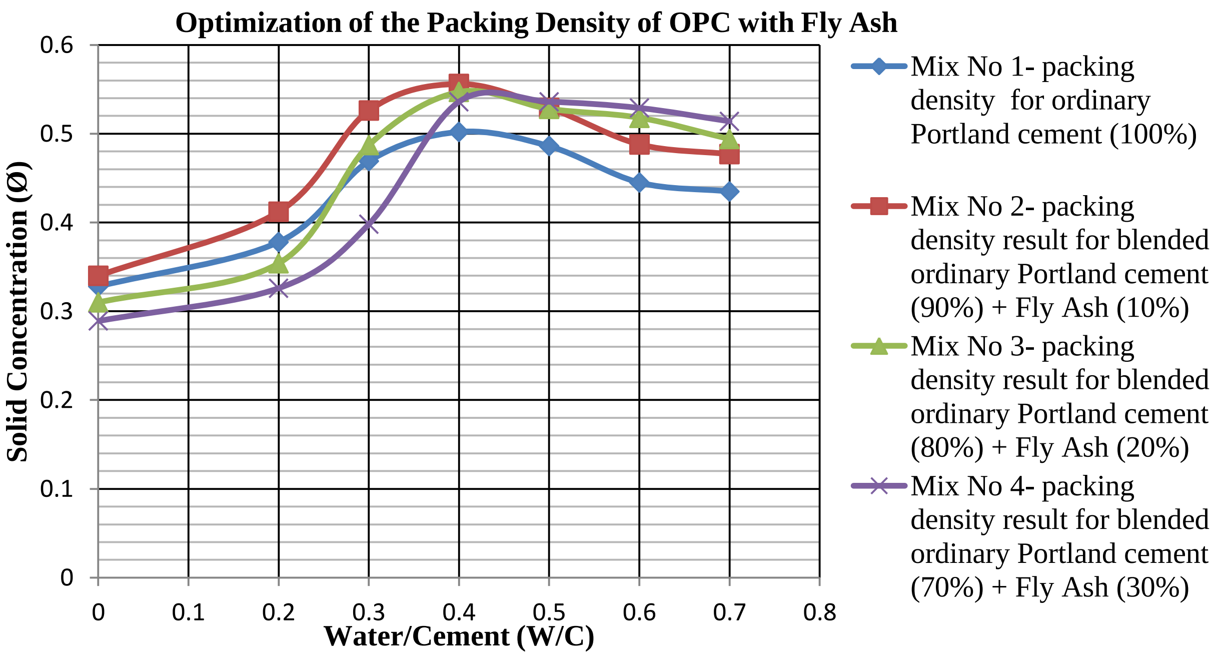

Figure 3.2: Optimization of the Packing Density of OPC with Fly Ash

3.3 Optimization of the Packing Density of OPC with Silica Fume (Micro Silica)

With the same mix proportions as used in fly Ash optimization, OPC was optimized using Silica Fume under the same conditions as shown in Figure 3.3. The best test result obtained was at a mix proportion of 80% OPC plus 20% SF and is compared to that of

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pure OPC in Figure 3.3 and Figure 3.5. It can be seen that blending OPC with Silica Fume will at all W/CM ratios significantly decrease the voids ratio and increase solid concentration and thus packing density. With 20% of the OPC replaced by an equal volume of Silica Fume, the maximum packing density increased from 0.502 to 0.619 (19% increase in the maximum packing density). The improvement in packing density may also in this case be attributed partly to the filling effect of Micro Silica, which reduces the voids volume by filling up the gaps between the OPC particles, and partly to the spherical shape of the SF particles, which allows better packing to be achieved [5]. Silica Fume is more effective than Fly Ash in improving the packing density of OPC because of the better filling effect arising from its ultra-high fineness.

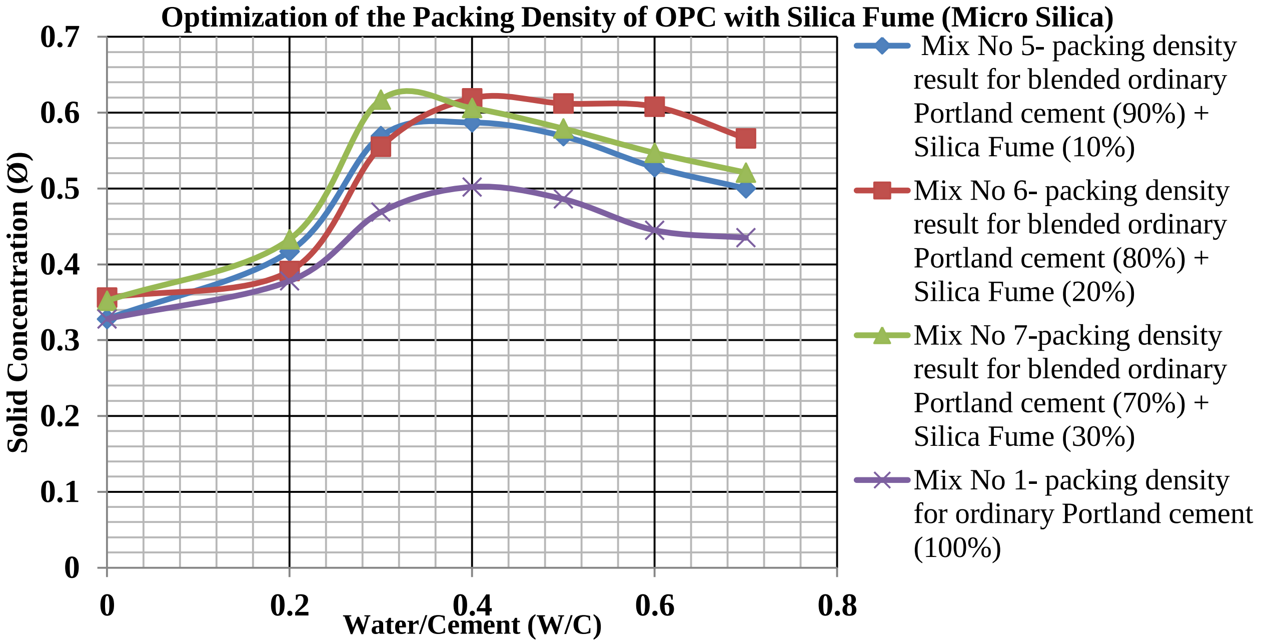

Figure 3.3: **Optimization of the Packing Density of OPC with Silica Fume (Micro Silica)**

3.4 Optimization of the Packing Density of OPC with Fly Ash plus Silica Fume (Double Blending)

To investigate the effect of double blending, a portion of the OPC was replaced with a mixture of Fly Ash and Silica fume in series of percentages, this optimization revealed that, doubly blending in an optimization series results in a higher packing density compared to singly blending as shown in Figures 3.2 and Figures 3.3 and Figures 3.5. It can also be observed from Figure 3.4 that the solid concentration of doubly blending FA and SF falls sharply beyond the optimum W/C ratio. The best optimization was achieved at OPC (70%) +Fly Ash (10%) + Silica Fume (20%).

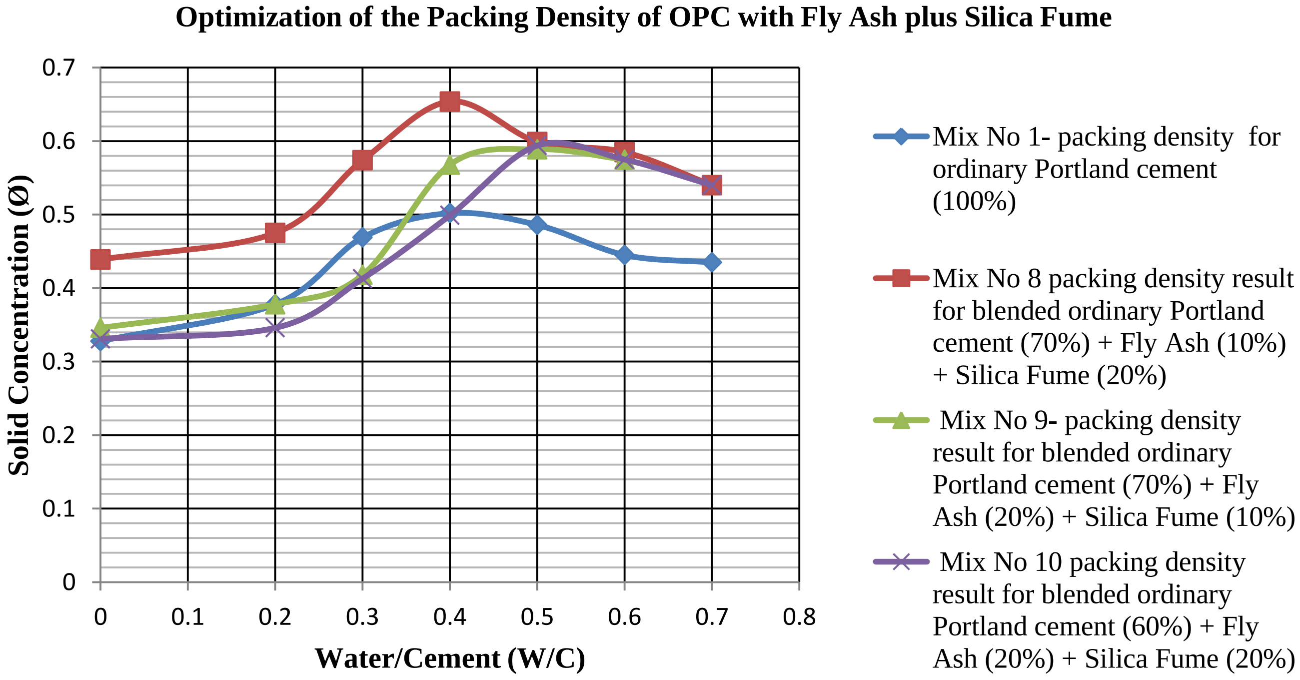

Figure 3.4: Optimization of the Packing Density of OPC with Fly Ash plus Silica Fume

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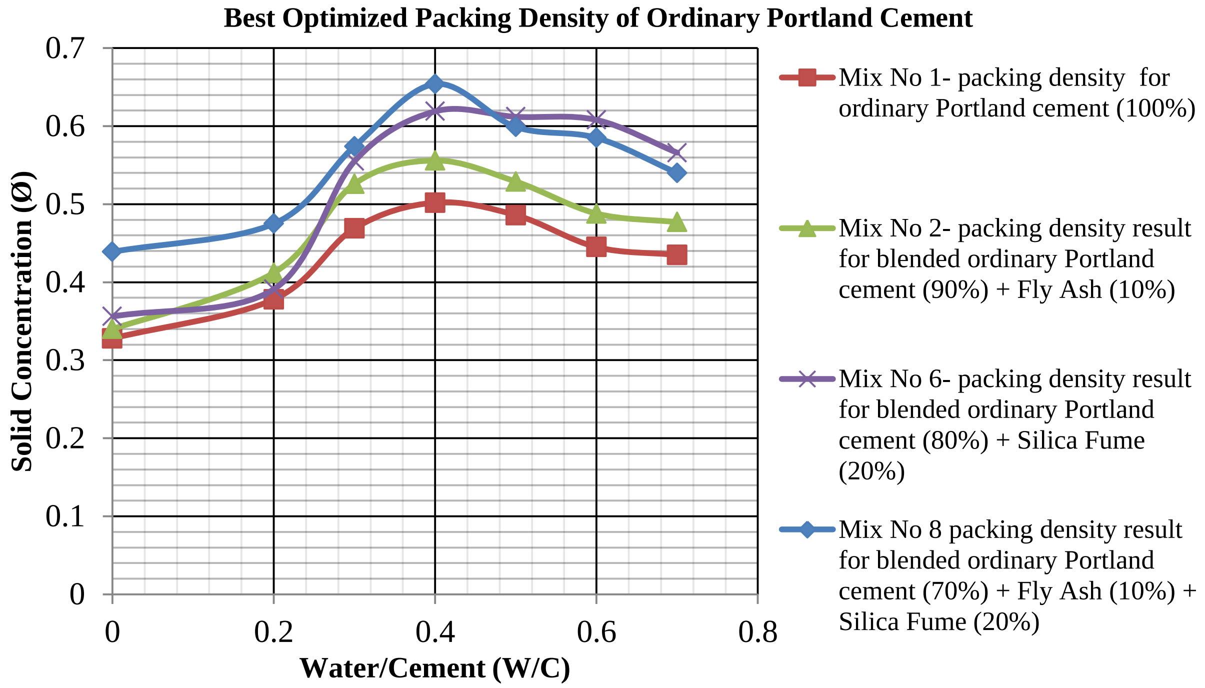

Figure 3.5: Best Optimized Packing Density of Ordinary Portland cement

3.5 Packing Density Optimization Of 20mm Coarse Aggregate (Wet packing)

The packing density of the 20mm coarse aggregate is seen to increase when blended with any proportion of smaller sized aggregates with maximum packing achieved at a mix proportion of 60% of 20mm plus 40% of 10mm aggregate sizes. This is because, the smaller sized aggregate fitted into the spaces created by matrix of the 20mm aggregate. Figure 3.6 shows the best optimized aggregates and their variation when packing density was determined using the wet and dry method. It can be seen that when the dry packing method was used, there was no significant increase in packing density when optimized having a maximum increase in packing density of 8.85%. However, when wet packing method was employed, the packing density optimization was determined to have increased by 15.43% at the same mix proportion; this indicates that wet packing method is more precise in the determination of packing densities because it takes into cognizance the effect of water in a concrete mix.

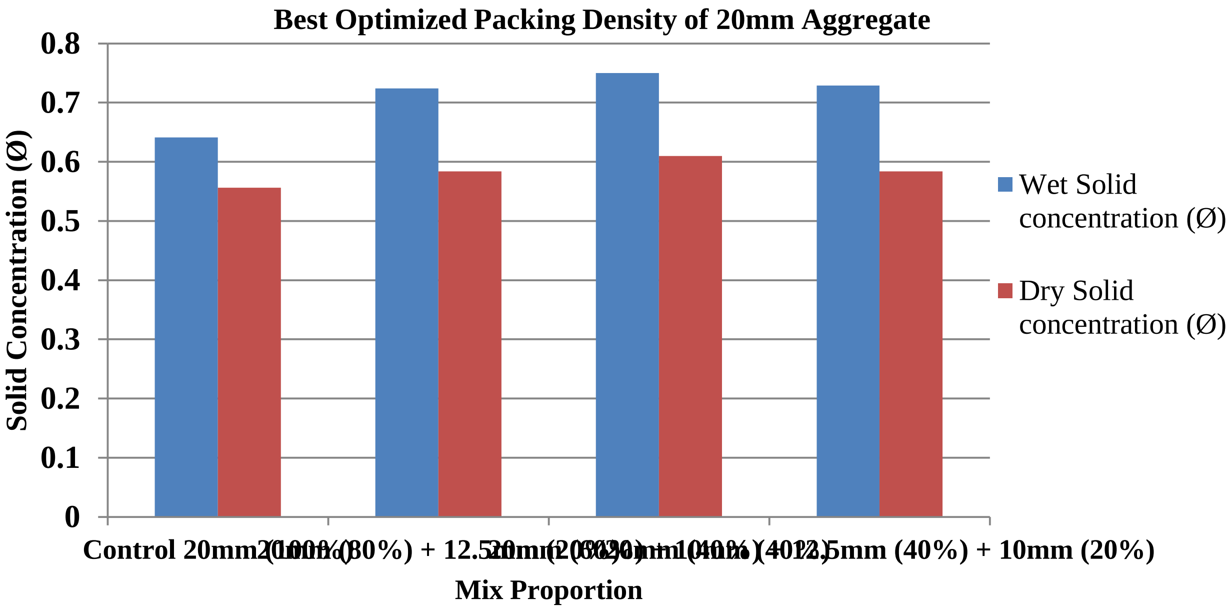

Figure 3.6: Best Optimized Packing Density of 20mm Aggregate

3.6 Particle size Distribution Analysis of 20mm Coarse Aggregate

The sieve analysis of the machine crushed granite (Figure 3.7) shows that it is gap graded (GP) with $C_u = 1.78$ and $C_c = 1$. For a gravel to be classified as well graded the criteria specifies that $C_u \geq 4$ and $1 < C_c < 3$. (ASTM, 1999)

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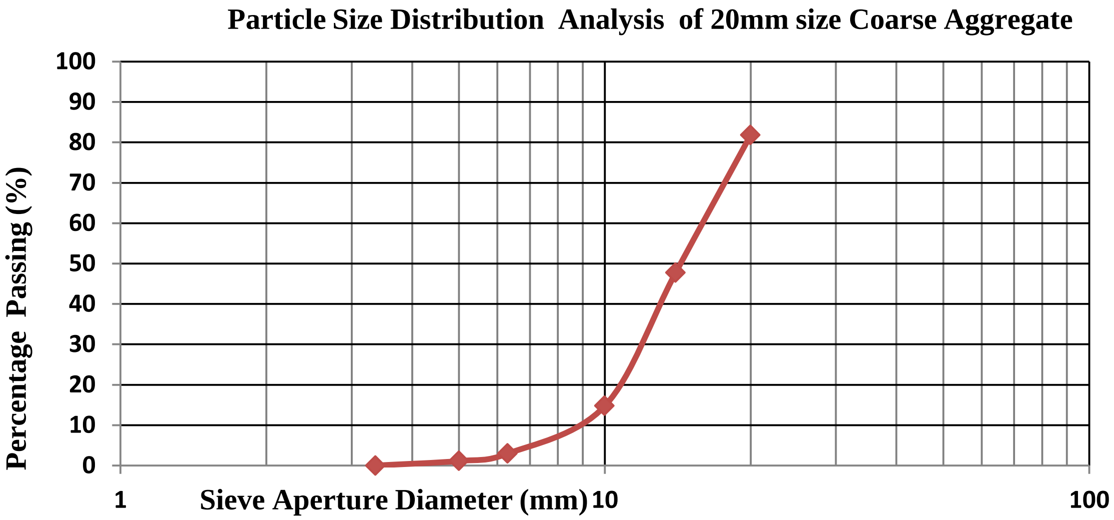

Figure 3.7: Sieve Analysis of 20mm size Coarse Aggregate

3.7 Particle size Distribution Analysis of Optimized 20mm Coarse Aggregate

Figure 3.8 shows a comparison of the particle size distribution of optimized aggregates against the 20mm sized aggregate (control). Improvement is seen in the uniformity (C_u) and gradation (C_c) of the optimized aggregates. This implies that the proportion of different sized aggregate present in the distribution has increased and thus reduced the void spaces in the aggregate matrix.

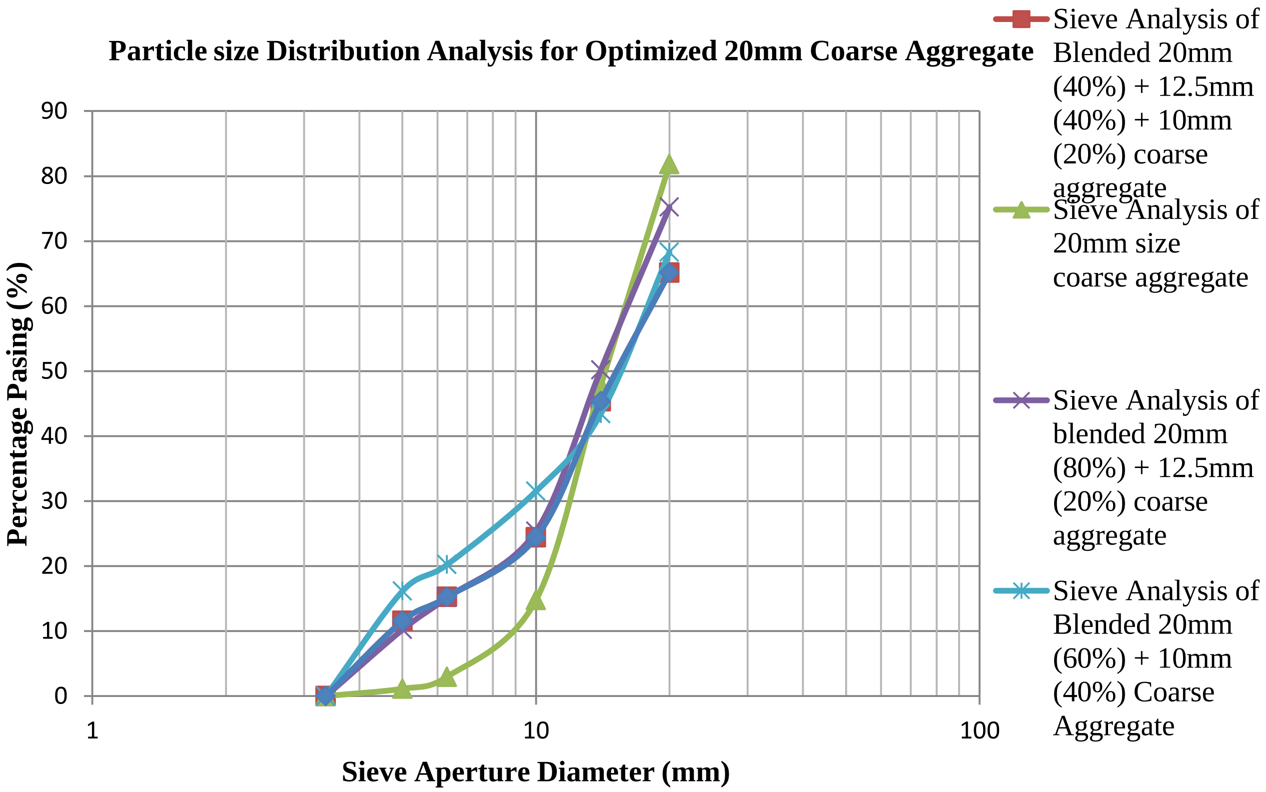

Figure 3.8: Particle size Analysis for Optimized 20mm Coarse Aggregate

3.8 Impact of Aggregate Packing Density Optimization on Concrete Cube Strength

To investigate the impact of aggregate packing on concrete, the best optimized aggregates were used in the concrete mix design for both grade M20 and M30 concrete, cured and tested under similar conditions. Figure 3.9 shows that the best aggregate packing (mix 004) resulted in a concrete strength that is 16.63% higher that the control strength (un-optimized) in 7-day strength and a 6.17% increase in the 28-day strength for grade M20. Figure 3.9 and 3.10 shows the 7-days and 28-days strength of aggregate optimized concrete for concrete grade M20 and M30 respectively.

3.9 Impact of ordinary Portland cement Packing Density Optimization on Concrete Cube Strength

This experimentation result from Figure 3.9 shows a decrease in strength for Fly Ash optimized mixes. This may be as a result of the low class of Fly Ash used. However, when OPC was optimized with 20% Silica Fume, an increase in strength of 4.27% (7

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days) and 2.78% (28 days) was observed for grade M20 concrete as shown in Figure 3.9 and a 5.14% increase in the 7-days strength and 6.19% increase in 28-days strength of grade M30 as shown in Figure 3.10. When 30% OPC was replaced by Silica Fume, 7-days and 28-days strength is observed to decrease.

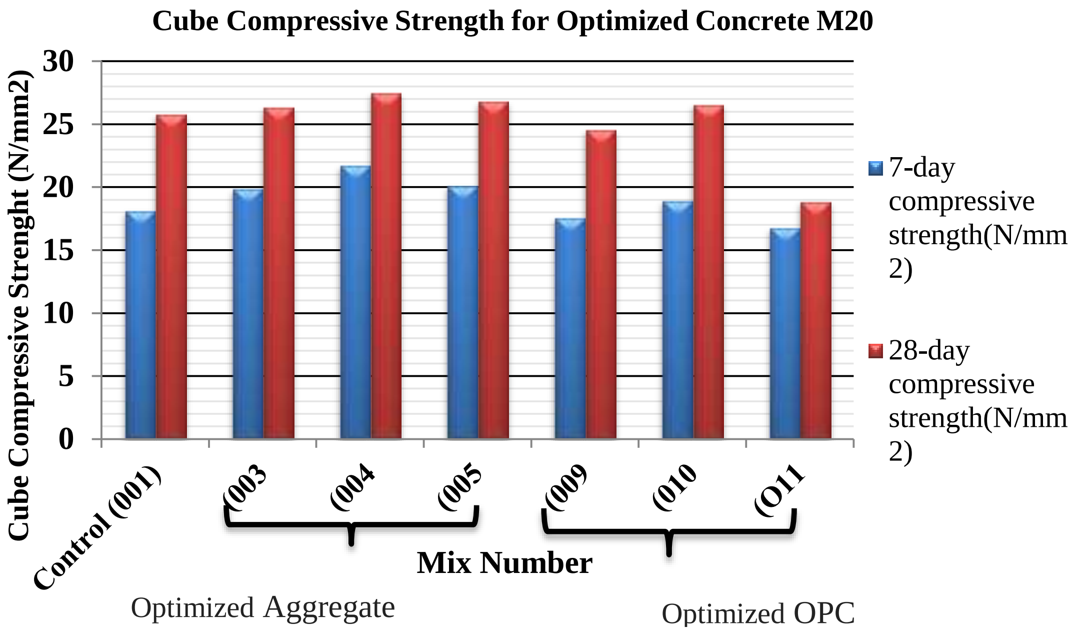

Figure 3.9: Cube Compressive Strength of Optimized Concrete M20

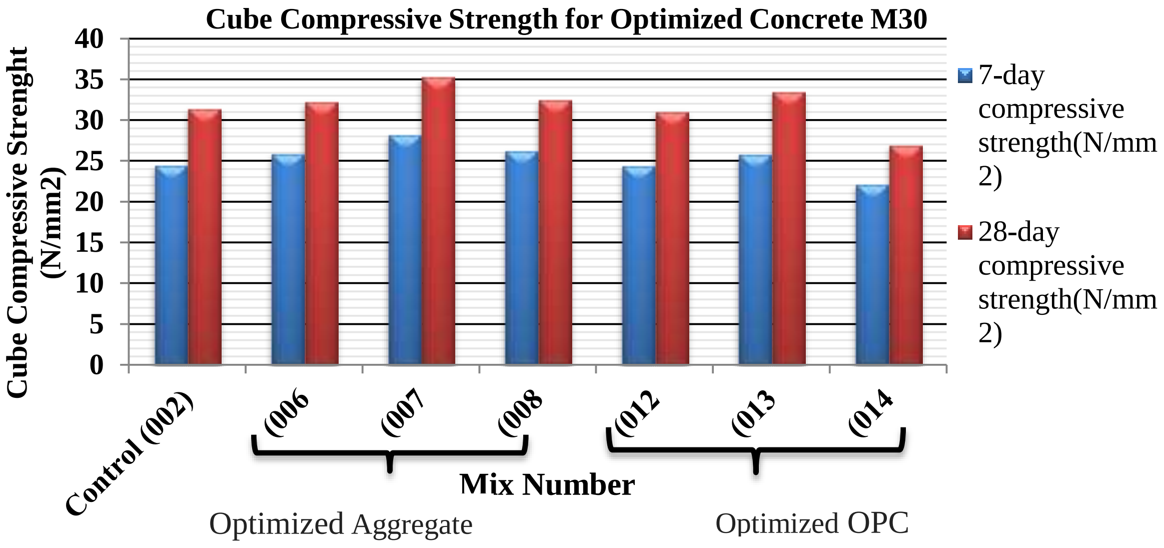

Figure 3.10: Cube Compressive Strength of Optimized Concrete M30

3.10 Water Absorption of Optimized Aggregate Mix

Table 3.1 shows the percentage of water absorption of concrete and percentage decrease in water absorption of optimized aggregate mixes after 28 days of curing of the hardened concrete made from various aggregate blends. The water absorption is seen to decrease with increase in packing density of aggregates as shown in Figure 3.11.

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Table 3.1: Water Absorption Result of Aggregate Optimized Mix

Mix Class	Mix N0	Wet Solid concentration (Ø) of Optimized Aggregate	Water Absorption (%)	Percentage Decrease In Water Absorption (%)
M20	Control (01)	0.641	4.14	-
	003	0.724	3.20	22.7
	004	0.750	3.05	26.3
	005	0.729	3.15	23.9
M30	Control (02)	0.641	3.30	-
	006	0.724	2.83	14.24
	007	0.750	2.62	20.6
	008	0.729	2.73	17.27

3.11 Water Absorption of Optimized Ordinary Portland cement (OPC) Mixes

Table 3.2 shows the percentage of water absorption of concrete and percentage decrease in water absorption of optimized OPC mixes after 28 days of curing of the hardened concrete containing various percentages of pozzolanas replacement.. The water absorption is seen to decrease with increase in packing density of OPC as shown in Figure 3.11

Table 3.2: Water Absorption Result of (Ordinary Portland cement) Optimized Mix

Mix Class	Mix N0	Wet Solid concentration (Ø) of Optimized Aggregate	Water Absorption	Percentage Decrease In Water Absorption
M20	Control (01)	4.14	4.14	-
	009	3.53	3.53	14.73
	010	3.19	3.19	22.9
	011	2.99	2.99	27.78
M30	Control (02)	3.30	3.30	-
	012	2.84	2.84	13.94
	013	2.64	2.64	20.00
	014	2.53	2.53	23.22

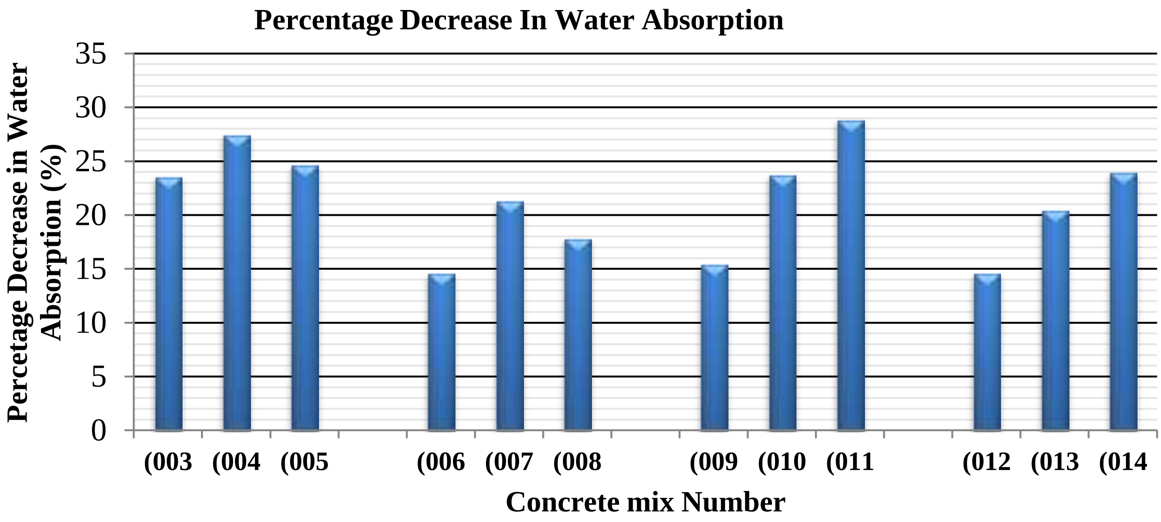

Figure 3.11: Percentage Decrease in Water Absorption of Mixes

3.12 Concrete workability- Compacting Factor and Slump

Optimization had no significant effect on the slump of concrete. In optimized aggregate mixes, the compacting factor was observed to increase with increase in packing density, irrespective of the grade of concrete. The compacting factor also increased with increase in packing density of optimized OPC irrespective of the grade of concrete. Reduced bleeding was observed and the concrete was more cohesive.

4. CONCLUSION

The results of the optimization experiment revealed best packing for ordinary Portland cement to be 0.654 for a mix proportion of OPC (70%) + FA (10%) + SF (20%) and best packing for coarse aggregate to be 0.750 for a mix proportion of 20mm (60%) + 10mm (40%). It is also evident from comparison of optimization results that the wet packing method was more sensitive in the determination of particle packing density. More so, because concrete is a mixture of cement, aggregate and water, the particle packing cannot be precisely determined without the addition of water. The advantage of this method is thus its sensitivity to the moisture content of a cementitious mixture [10].

The results also show that the best optimized aggregate resulted in a concrete strength increase of 16.63% for 7-days strength and a 6.17% increase in the 28-days strength for grade M20. When OPC was optimized with 20% Silica Fume, an increase in strength of 4.27% (7 days) and 2.78% (28 days) was observed for grade M20 concrete. Water absorption is seen to decrease up to 23.22% as the packing density increased. The strength of concrete is seen to improve for silica fume optimized mixes and decrease for mixes containing fly ash. This is because of the chemical compositions of the respective oxides. Silica fume contains a higher percentage of silicon oxide (SiO_2) while the fly ash has a high loss on ignition. It is thus expected that the concrete containing silica fume will have higher strength. Concrete strength is also seen to improve as the packing density of the aggregate increased, in other words optimization of the packing density of aggregate leads to an increase in the strength of concrete. The water absorption of concrete using optimized aggregates and ordinary Portland cement was seen to decrease with increase in packing density. This implies that improving the packing density of concrete increases its strength property, its durability and thus its resistance to chemical attack and overall performance. The results shows that, improved packing density implies reduced water absorption and in some cases, improved strength. Based on these results, packing density optimization is recommended for the design of high performance or special concrete. Double blending is recommended for cementitious materials and coarse Aggregate optimization. High purity fly ash such as class “F” fly ash is recommended if strength is a major factor. For further research, a wider range of mix proportions should be tested to provide for a better optimization program of aggregates and OPC.

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