Effect of Water-Cement Ratio on Compressive Strength of Spray Cured Concrete

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Abstract

Different water cement ratios are usually adopted to produce concrete elements depending on the strength and workability intended to achieve. However, their strengths partly depend on the w/c ratio, degree of compaction, method and duration of curing. The structural or engineering performance of concrete depends largely on its strength, particularly compressive strength and therefore proper attention is needed in the process of hardening of concrete. Preliminary tests were carried out on aggregates and cement to established mix design (British method) and concrete cubes were cast at water-cement ratios ranging between 0.45 and 0.75 and to examine their effects on the compressive strength of concrete. A total of 175 cubes were cast with 25 each for various mix ratios. The cubes were cured using spray curing method in the laboratory at room temperature. The results indicate that the average compressive strength values for 28-day curing varies with water cement ratio. The compressive strength of specimen decreases with increase in water – cement ratio. The water- cement ratio of 0.45 produced the concrete with highest compressive strength of 36.46 N/mm^2 at 28 days while 0.75 w/c ratio produced concrete with the least compressive strength of 13.30 N/mm^2 at the same curing age. It was concluded that the use of water – cement ratio above 0.60 should be discouraged since it produces concrete with compressive strength below 21 N/mm^2 which is the minimum required compressive strength value specified by the National Building Code.

Keywords: *Compressive strength, Concrete, Spray curing, Water-cement ratio*

Introduction

Concrete is the most widely used construction material in construction industry. Conventionally, concrete is a mixture of cement, fine aggregate, coarse aggregate, water and sometimes admixtures in the required proportion to get a required strength. The compressive strength of hardened concrete depends on quality and quantity of cement, aggregates, water; batching, mixing, placing, compaction and curing techniques.

Obviously, the quality of concrete in construction works is determined in terms of its 28 days compressive strength and if after 28 days, the required quality of concrete is not achievable, then the process of concrete production should be critically re-examined. The need for having a reliable water - cement ratio that will meet the minimum required specified compressive strength is of great importance.

Occasionally, there are cases involving the collapse of both fresh and hardened concrete elements during and after the construction and series of investigation revealed that the principal causes of this concrete elements failure are as a result of poor concrete strength. However, concrete strength depends primarily on water-cement ratio and degree of compaction regardless of their mix proportion. In view of this, the research work investigated the effect of W/C ratio on the compressive strength of concrete.

Obviously, the compressive strength of concrete is usually greater than its tensile strength. However, Mosley and Bungey (2000) found that the compressive strength of concrete is about eight times greater than the tensile strength. In most common structural elements, the tensile strength of concrete is neglected during the design. Although, in the design of some structures that will occupy liquids the tensile strength is taken into account. In fact, good and standard concrete regardless of its type should be strong enough to carry the designed superimposed loads during its designed life span.

Other properties of concrete to be considered include permeability, cracks, shrinkage, durability, surface wear and cavitation. Varma (2015) revealed from the investigation carried out on the effect of change in water-cement ratio on wet density, dry density, workability and compressive strength of M-20 grade concrete that increase in water-cement ratio causes decrease in compressive strength of concrete mixes. However, the compressive strength of concrete mixes increases with age. The author also pointed out that water-cement ratio above 0.55 was found to cause a very significant reduction in the compressive strength of the concrete mixes, hence, strict control on the water cement ratio on site is very paramount to achieving good quality concrete.

Omotola and Idowu (2011), conducted an investigation into the effects of water-cement ratio on the compressive strength and workability of concrete and lateritic concrete mixes and discovered that, increase in water-cement ratio causes reduction in the compressive strength of both concrete and lateritic concrete mixes. However, the compressive strength of both concrete and lateritic concrete mixes increases with age. The authors also observed that the water-cement ratio above 0.65 was found to cause a very significant reduction in the compressive strength of the lateritic concrete mixes and for 0.80 water-cement ratio, the water content was such that the fluidity of the mixture is large enough to cause collapse of the concrete cone but not in the lateritic - concrete cone.

Nyiutsa *et al*. (2013) investigated the effect of water-cement ratio on the compressive strength of gravel - crushed over burnt bricks concrete and concludes that, reducing the water-cement ratio increases the compressive strength of concrete. Hamed and Omolbanin (2012), studied the effect of water- cement ratio (w/c) on mechanical properties of self-compacting concrete (case study) and discovered that by decreasing the water/cement ratio in self-compacting concrete (SCC) for mixes up to 0.45, compressive strength, tensile strength and modulus of elasticity will improve and that the water/cement ratio more than 0.55 and less than 0.45 are not useful for SCC mix designs. Rashid *et al*. (2009) conducted a research on the properties of higher strength concrete made with crushed brick as coarse aggregate and reported that higher strength concrete (fcu = 31.0 to 45.5 N/mm^2) with brick aggregate is achievable and its strength is much higher than the parent uncrushed brick implying that the compressive strength of brick aggregate concrete can be increased by decreasing its water-cement ratio.

Himanshu (2016) researched on the establishment of water cement ratio curve for set of materials and concluded that water/cement ratio plays a very important role in concrete and that as the water content in cement paste reduces, strength increases. It was observed also that higher strength concrete can be achieved at low water content. Akeem *et al*. (2013) investigated the effect of curing methods on density and compressive strength of concrete and discovered that the average compressive strength of concrete specimens cured by water spray curing method were 13.6, 15.0, 17.2, 19.7 and 23.6 N/mm2 after 3, 7, 14, 21 and 28 days of curing respectively. The author also revealed that of all the methods of curing used in the investigation, except air curing method produced concrete specimens that met the minimum compressive strength of 21 N/mm2 at 28 days as specified by National Building Code (2006).

Shamsai *et al*. (2012) investigated into the effect of Water-Cement Ratio in

Compressive and Abrasion Strength of the Nano Silica Concrete and the results showed that due to reduction of water-cement ratio from 0.33 to 0.50, the compressive strength improved by 34.4 and 35.2 %, respectively.

Water-cement ratio can be used as an evaluation technique to know whether the actual concrete composition complies with the job specifications or not and also to check the uniformity of the concrete within or between batches. The advantage associated with using such a check method is that, concrete can be analyzed instantly at the point of delivery to the jobsite. Thus, this allowed the site engineer to take a decision on whether to reject the concrete mix if it does not meet the project specifications before it becomes an integral part of the project.

It is therefore, on this background that the aim of this research work is to investigate the effect of water- cement ratios on compressive strength of concrete using spray curing method and this could be achieved with the objectives as to:

1. Determine the physical properties of sample aggregates (fine and coarse); 2. Produce concrete cubes using different water- cement ratios (between 0.45 and 0.75);

3. Determine the compressive strength of concrete at the ages of 3, 7, 14, 21 and 28 days.

Materials and Methods

Materials

Materials used in this research are aggregates (crushed granite and river sand), Ordinary Portland cement (OPC) and portable water. They were source in Minna and its environs, Niger State, Nigeria.

Coarse aggregate

Crushed granite chippings of nominal size ranging between 5mm and 19mm obtained from Triacta quarry site in Minna, Niger State, Nigeria was used as coarse aggregate. The aggregates were passed through sets of sieves to ascertain their particle sizes before usage. The sizes passing through sieve 20mm and retained on sieve 5mm were used. The test procedures were conform in accordance with BS 882: Part 2 (2002). Fine aggregate

Natural river sand used was collected from its abundant deposit site at River Paiko, Niger State, Nigeria. The material was air-dried in the laboratory platform to reduce excess moisture before use. Natural sand may produce conventional concretes that are more workable than those of manufactured fine aggregate. In this concrete production, it was ensured that the sand was clean, sound and free of impurities in accordance with grading requirement of AASHTO T 27 (2014).

Cement

The Dangote Ordinary Portland Cement (OPC) of grade 42.5R was used, being the most widely cement type that is readily available in the Minna market. It did conform to code specification for Portland cement by BS EN 197-1 (2001). All necessary precautions were taken to protect the cement from dampness to avoid caking (lumps). The net weight of each bag was fifty kilogram (50kg).

Water

Water that is clean and safe for drinking was used during the experimental work and was sourced directly from tap in the laboratory. The water used particularly for mixing and curing was free from harmful amounts of acids, alkalis and organic materials, and conforms to BS EN 1008, (2002) requirements.

Methods

Sieve analysis

The sieve analysis or grading tests for both River sand and the crushed granite were carried out as prescribed in the AASHTO 27, (2014).

Bulk density

Bulk density tests on River sand and crushed granite were carried out in accordance to AASHTO T 19 (2014) while that of cement was conducted to ASTM C 188, (2015) specification.

Specific gravity

Specific gravity tests were conducted on both aggregates in accordance with procedures in AASHTO T 84, (2013) and AASHTO T 85, (2013) respectively. However, the specific gravity of cement used was determined according to ASTM C 188, (2015).

Aggregate crushing and impact value tests

Aggregate crushing and impact value tests were also conducted on crushed granite to ascertain its resistance to static and dynamic loads in accordance to BS 812: Part 110 and 112 (1990) respectively.

Preparation of concrete and test cube specimens

The concrete mix ratios adopted was achieved through British Mix Design Method (DoE) and proportioning of concrete constituents were estimated using the targeted mean strength corresponding to W/C ratios of 0.45, 0.50, 0.55, 0.60, 0.65, 0.70 and 0.75.

The fresh concrete was prepared manually through mixing of sand, cement and the crushed granite with the specified quantity of water. The fresh concrete was then cast into 150mm by 150 × 150 × 150 mm moulds in three equal layers and a total number of 175 concrete cubes were cast. The whole procedures were carried out in accordance with BS EN 12390-2 (2009). The specimens were demoulded after 24 hours.

Curing

The cast 175 concrete cubes were demoulded after 24 hours and were subjected to spray curing method which was done twice daily in the laboratory for a maximum period of 28 days in accordance to BS EN 12390-2 (2009).

Compressive Strength test

Compressive strength test was carried out on cubes at the curing ages of 3, 7, 14, 21 and 28 days respectively, in accordance with BS EN 12390-3, (2009) specifications and the results were analyzed accordingly using relevant formula.

Results and Discussion

Physical properties of cement and aggregates

The results of physical property tests of concrete constituents are shown in Table 1.

Bulk density

The un-compacted bulk densities of sand, gravel and cement are shown in Table 1. Neville (2008), specified the range of uncompacted to compacted bulk density ratio to fall between 0.87 and 0.96. From the above results, their respective un-compacted to compacted bulk density ratios are 0.93, 0.89 and 0.88. Since the results fall within the range specified by Neville (2008), this implies that the constituents are closely packed together.

Porosity

The porosities for sand and gravel are shown in Table 1 and according to Neville (2008), the porosity ranges between 0 and 50 Percent for common rocks. It can be deduced from the result that, materials used are suitable since they are within the specified range. This can also give a satisfactory interlocking of concrete constituents and effective filling of minor pore spaces by cement paste. In fact, the low value of porosity recorded indicates free harmful chemicals in the materials and this reduces the corrosion effect of reinforcing steel and increase durability of concrete Neville (2008).

Specific gravity

Also from Table 1, it can be seen that the specific gravities of sand, granite and cement are within the acceptable range of

2.40 and 2.60 for sand while that of granite is 2.60 and 3.0 as specified by Neville (2008). This shows that the concrete produced from these materials would have a density of normal concrete since the values falls within the range of aggregate specific gravity from rock fragments and is similar to values obtained by Abdullahi (2012). This indicates that the aggregates can be useful in construction work.

Void ratio

The void ratio results obtained from this research work for fine and coarse aggregates were 0.48 and 0.43 respectively. To achieve a good quality concrete, it is obviously required that all the voids created by coarse aggregate be filled with specified mortar to improve hardness and strength development of concrete. Moreover, it also minimizes honey-combing that makes the concrete un- aesthetically appealing.

Aggregate crushing value (ACV) and Aggregate impact value (AIV)

The aggregate crushing value (ACV) and aggregate impact value (AIV) for crushed granite used were found to be satisfactory. This indicates that the aggregate has good resistance to both static and dynamic loads. The percentages obtained for both ACV and AIV falls within the range specified by BS 812 (1990), which recommends the maximum value of 30% for ACV and 25% for AIV respectively.

Table 1: Physical properties of cement and aggregates

Description	Cement	Fine aggregate	Coarse aggregate
Loose dry bulk density (kg/m^3)	824.72	1344.86	1547.84
Compact dry bulk density (kg/m^3)	964.18	1444.91	1731.98
Specific gravity	3.24	2.60	2.71
Aggregate crushing value (%)	-	-	28.61
Aggregate impact value (%)	-	-	18.03
Void ratio	0.75	0.48	0.43
Porosity (%)	14.46	6.92	10.63
Fineness Modulus	-	2.97	3.13
Coefficient of uniformity(Cu)	-	2.50	1.60
Coefficient of curvature (Cc)	-	1.02	1.10

Sieve analysis River sand - fine aggregate

The particle size distribution curve for the sharp sand is shown in Fig. 1 and from the result it was deduced that the sand falls in the category of Zone 3 since the percentage passing 600μm was 70.43%.The material contains some identifiable portion of coarse materials and is considered well graded since it has the values of Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc) of 2.50 and 1.02 respectively. These values are similar to that obtained by Akeem *et al*.

(2013).

Coarse aggregate

The particle size distribution curve for crushed granite aggregate is shown in Fig. 2 and it can be seen from the Figure that the aggregate is uniformly graded since its Coefficient of Curvature (Cc) which is 1.10 falls between 1 and 3. The maximum size of the crushed granite is 20 mm.

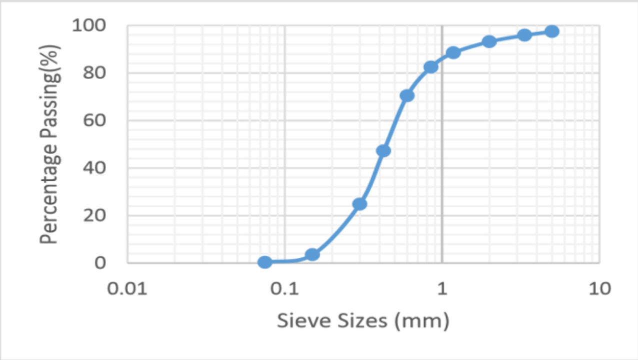

Fig. 1: Particle size distribution curve for fine aggregate

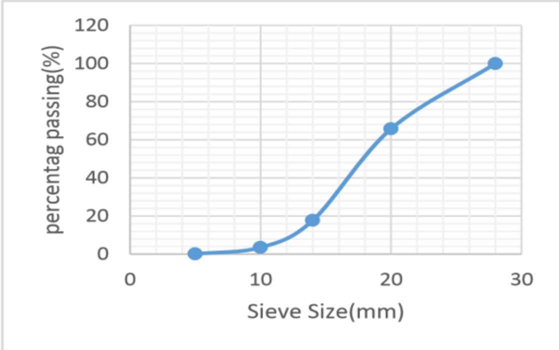

Fig. 2: Particle size distribution curve for coarse aggregate

Compressive Strength

The summary of compressive strengths of concrete for different water cement ratio used in the investigation at various curing ages are shown in Table 2 while the detailed 28 days compressive strength for various water - cement ratios is shown in Table 3. This is similar to the result obtained by Akeem *et al.* (2013). The mean compressive strength achieved from water cement ratio of 0.45 is almost two and three times higher than the strengths gained from 0.60 and 0.75 water cement ratios respectively. This indicates that the water cement ratio of 0.65 and below can be used effectively to achieve the minimum required compressive strength specified in National Building Code, (2006). However, due to large size and positions of some concrete elements, the use of spray curing method could be adopted provided water cement ratio does not exceed 0.65

Table 2: Average Compressive Strength of Concrete Cubes

W/c	Average compressive strength (N/mm^2)					Target design strength at 28 day (N/mm^2)	Percentage achieved at 28 day (%)
	3 day	7 day	14 day	21 day	28 day		
0.45	21.93	30.11	31.98	33.39	36.46	49.0	74.41
0.50	18.27	22.65	23.29	26.01	29.40	43.0	68.37
0.55	16.27	18.99	22.06	24.04	25.58	39.0	65.59
0.60	15.73	17.31	20.35	21.88	23.79	38.0	62.61
0.65	11.06	12.04	16.43	17.42	18.86	34.0	55.47
0.70	08.24	10.17	13.12	15.15	16.53	30.0	55.10

Table 3: Compressive strength result for cubes cured at 28 days

W/c ratio	Failure load (KN)	Compressive strength (N/mm²)	Average compressive strength (N/mm²)
	792	35.20	
	830	36.89	
0.45	842	37.42	36.46
	812	36.09	
	826	36.71	
	670	29.78	
	640	28.44	
0.50	664	29.51	29.40
	656	29.16	
	678	30.13	
	580	25.78	
	574	25.51	
0.55	584	25.96	25.58
	572	25.42	
	568	25.24	
	540	24.00	
	522	23.20	
0.60	552	24.53	23.79
	516	22.93	
	546	24.27	
	390	17.33	
	440	19.56	
0.65	428	19.02	18.86
	448	19.91	
	416	18.49	
	374	16.62	
	364	16.18	
0.70	382	16.98	16.53
	368	16.36	
	372	16.53	
	302	13.42	
	296	13.16	
0.75	294	13.07	13.30
	306	13.60	
	238	13.24	

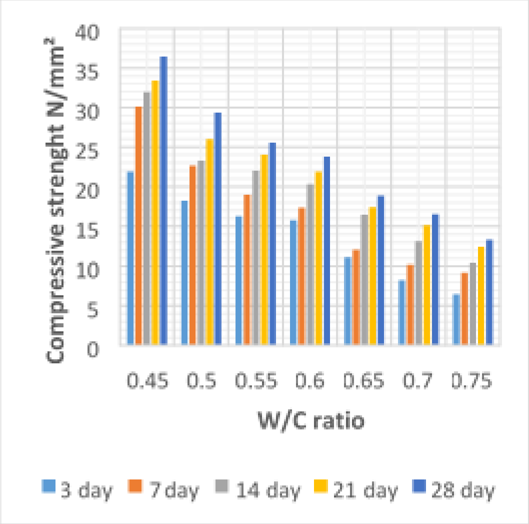

Fig. 3: Comparison of compressive strength for different water - cement ratio

Conclusion

Based on the analysis of results obtained from the effect of water- cement ratios on compressive strength of concrete using spray curing method, it can be concluded that:

The constituents are closely packed together, free of harmful chemicals and are suitable for construction or normal concrete work. The coarse aggregate used has good resistance to both static and dynamic loads and is uniformly graded The average compressive strength values at different curing ages varies with water-cement ratio and the mean compressive strength recorded from water cement ratio of 0.45 is almost twice and thrice higher than the strengths gained from 0.60 and 0.75 water cement ratios respectively. This shows that compressive strength increases with an increase in age of curing and decreases as the water cement ratio increases. That is, higher strength concrete can be achieved with low water content. It is also concluded that water cement ratio plays an important role in manufacturing of concrete as far as compressive strength of concrete is concerned. More so, in other to achieve good quality concrete, strict control on the water cement ratio on site is very much required. Of all the water-cement ratios considered, except 0.65 and above, produced concrete that met the minimum compressive strength of 21N/mm2 specified by the National Building Code, (2006).

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