Improvement of Compressive Strength of Concrete by a Two-phase Mixing Method

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ABSTRACT: The variation in the strength of concrete and allied products may be attributed to high variation in the properties of aggregate used, quality of cement, environmental conditions, and batching procedures (mixing method). It's been noted, that batching error accounts for the larger percentage of variability of concrete strength. Thus this project, the advance preparation (premixing) of "Cement Paste" and "Grout" separately, which is then blended with aggregate to produce concrete otherwise called "Two-Phase Mixing Method", was investigated. The objectives of premixing is to eliminate undissolved cement particles, enhance hydration, coat the surface of all aggregate particles with the cement paste or grout, and to blend all the ingredients of concrete into a uniform mass. A total of 90 cubes of 15x15x15cm cube mould were cast, with 18 as control sample cubes for conventional concrete mixing and 36 cubes each for the Two-phase concrete premixing (Cement Paste and Grout). Concrete mixtures of three water-cement ratios (0.40, 0.45, and 0.50) were included in the experimental program. The quantity and quality of cement, aggregate and additive was kept constant with a mix proportion of 1:2:4. Each cube also contains 1.29kg of cement and 0.026kg of superplasticizer (representing 2% of cement weight) for all concrete mixture. Laboratory investigation also included two mixing speeds (25rpm and 32rpm) and Seven (7) to Twenty-eight (28) curing days. Results show that premixing of Cement Paste concrete has the highest compressive strength with 33.78N/mm^2, which represents 21.9% increase over that of the control sample with 27.71N/mm^2 for 0.40 water/cement ratio at 28days. While Grout premixing method only managed a 1.05% increase with 28.00N/mm^2. Also, 32rpm mixing speed recorded about 16% to 19% increase in compressive strength over 25rmp mixing speed.

Keywords: Concrete, Cement Paste, Grout, Superplasticizer, Agglomeration, Premixing, Revolution per minute, Compressive Strength, Two-phase Mixing Method

1.0 INTRODUCTION

Thorough mixing of concrete ingredients is essential to producing a homogeneous mixture that permits uniform particle distribution and hydration of cement particles in the concrete system.

A fine cementitious material, low water-to-binder ratio, and high binder content are increasingly common in modern concrete, the agglomeration of fine cementitious particles often occurs, which not only impairs the uniformity of hydration of cementitious materials, but also reduces the workability of concrete. Also important is the proper coating of the aggregates in the mixing operation with proper paste that eliminates undissolved cement particles. **Schaefer et al (2007)**

Hence, optimal quality mixing becomes increasingly important and a method or technique is needed to help ensure the optimum quality of cement paste and coating of the aggregates. One such method is a two-phase process in which the first phase consists of premixing water, cement and additives to prepare the paste and the second phase consists of coating the aggregate. The concept is to allow the cement and the additives to chemically combine with water in an adequate manner. By

not allowing the cement and additives' undissolved particles to attach to the aggregate, the coating of the aggregate in a separate operation should improve, along with the uniformity of the paste between the aggregate particles.
Traditional concrete mixing practice today is regulated by a specific mixing time required to achieve specified performance of the fresh and hardened concrete. The mixing time is based on a long experience of developed correlations between the mixing process and the concrete performance, and is generally detailed in specifications. The effect of the mixing procedure on the materials in concrete is an important area of research. A complete understanding of these procedures on a step-by-step basis, in theory and through empirical relationships, will lead to increases in the efficiency of the mixing process and improvements in concrete properties.

A two-phase mixing process for concrete, involves mixing a slurry of the cementitious materials (cement + water paste, and/or cement + sand + water grout), then adding the slurry to the coarse and fine aggregate or/and adding the grout to the coarse aggregate to form concrete with varying mixing energy. The technology of cement paste preparation by high intensity mixing is being researched and used presently. Although it is not new in the industry, but then; more and more research is needed to be done in this area of concrete technology.

It is believed that the pre-mixing process might facilitate dispersion of cementitious material and improve cement hydration, concrete homogeneity, and the interfacial transition zone (ITZ) between aggregate and paste. **Schaefer et al (2007)**

Concrete is the basic engineering material used in most of the civil engineering structures. It surpasses the other construction materials with respect to flexibility of shape, strength and durability and response to its environment. Its popularity as basic building material in construction is because of its economy of use, good durability and ease with which it can be manufactured at site. The ability to mould it into any shape and size, because of its plasticity in green stage and its subsequent hardening to achieve strength, is particularly expedient.

Concrete like other engineering materials needs to be designed for such properties like strength, durability, workability and cohesion. However, despite these laudable characteristics the quality of concrete is not easily controlled. The variation in the strength of concrete and allied products may be attributed to high variation in the properties of aggregate used, quality of cement, environmental conditions, and batching procedures (mixing method). It's been noted, that batching error accounts for the larger percentage of variability of concrete strength. **Obla (2012)**

As a result of this difficulty in quality control of concrete production in Nigeria today, which has amounted to abrupt and incessant collapse or failure of buildings and structures across the country (with due considerations to adequate structural design and supervision). This is worrisome and therefore demands more attention and research as to improving the strength and quality of concrete and concrete structures.

Presented in this work, is an alternative step-by-step for optimal mixing procedures for production of a homogeneous and workable mixture and quality concrete using a two-phase mixing operation.

2.0 MATERIALS AND METHOD

2.1 DETAILS ON MATERIAL SELECTION

The constituent materials used in this research are cement, coarse aggregate, fine aggregate, water and superplasticizer.

Cement

The same commercially available Type C35, Portland cement with fly ash (Polish production) was used in all the experiments. It was homogenized and stored in the laboratory room to maintain the same quality throughout the test period.

Aggregates

The coarse and fine aggregate used in this research were commercially available materials, from natural sources. The fine-coarse aggregate ratio was kept constant (0.5) for all concrete mixes. The type of coarse aggregate used is angular aggregates with rough surfaces. The coarse aggregate is also a crushed aggregate with 20mm average size. For optimum compressive strength with high cement content and low water/cement ratio, the maximum size of coarse aggregate should be kept to minimum at 12.7mm or 9.5mm.

Water

In this study, water used in mixture of concrete, including free water on the aggregates, was obatined clean and free from impurities of oils, acids, alkalis, salts, organic material or other substances that may be deleterious to concrete.

Superplasticizer

Superplasticizer used is known as CONPLAST SP430 liquid. It is a type of sodium salt of polynaphthalene sulfonic acid. The physical appearance of CONPLAST SP430 liquid is shown in Figure 2.1 and its colour appears dark brownish. Strength of concrete is inversely proportional to the amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water is added, which makes the concrete mixture very unworkable and difficult to mix, necessitating the use of plasticizers, water reducers, superplasticizers or dispersants. For all mixtures the percentage of superplasticizer was 2% by weight of cement and this was kept constant throughout the mix.

Figure 2.1(a) & (b) Sample of CONPLAST SP430 liquid Superplasticizer used

Adding 2% of superplasticizer per unit weight of cement is adequately sufficient. However, most commercially available superplasticizers come dissolved in water, so the extra water added has to be accounted for in mix proportioning. Adding an excessive amount of superplasticizer will result in excessive segregation of concrete and is not advisable.

2.2 EXPERIMENTAL PROGRAM

Mix Ratio

Concrete mixtures of three water-cement ratio (0.40, 0.45, and 0.50) were included in the experimental program. The quantity of cement and additive was kept constant with each cube containing 1.29kg of cement and 0.026kg of superplasticizer (2% of cement weight) for all concrete mixture.

Table 2.1 Summary of constituent by weight for cube size $0.15m^3$

Material	1cube of $0.15m^3$	6cubes of $0.15m^3$	90cubes of $0.15m^3$
Cement	1.29 kg/m^3	7.75 kg/m^3	116.25 kg/m^3
Sand	2.58 kg/m^3	15.5 kg/m^3	232.55 kg/m^3
Coarse aggregate	5.17 kg/m^3	31.0 kg/m^3	465.12 kg/m^3
Superplasticizer	0.026 kg/m^3	0.156 kg/m^3	2.33 kg/m^3

Mixing Method

1. **Two-phase Mixed Concrete (Pre-mixing of cement Paste):** Water, superplasticizer and cement were mixed using high-speed and low-speed mixing rates of 32rpm and 25rpm respectively for 2minutes. The resulting cement paste and grout was mixed with aggregate for 2 minutes, using low-speed mix rate of 25rpm. (Mixing speed is very crucial during the phase one mixing process, this is because the cement particles are adequately dissolved and hydration is enhanced by applying a high mixing speed). Hence, 25rpm and 32rpm were compared during premixing of phase one.

Cement + Water + Admixture = PASTE
(Phase One Premixing for 2minutes)
+
Sand + Granite
(Phase Two finial mixing for 2minutes)
↓
CONCRETE

2. **Two-phase Mixed Concrete (Pre-mixing of Grout):** Water, superplasticizer, cement and sand were mixed using high-speed and low-speed mixing rates of 32rpm and 25rpm respectively for 2 minutes. The resulting grout was then mixed with coarse aggregate for 2 minutes, using low-speed mix rate of 25rpm.

Cement + Sand + Water + Admixture = GROUT
(Phase One Premixing for 2minutes)
+
Granite
(Phase Two finial mixing for 2minutes)
↓
CONCRETE

3. **Control Mixed Concrete:** All mixtures were prepared using a normal mixer. The coarse aggregate, sand and cement were mixed together by a conventional method for 0.5minute, and then the water and superplasticizer were added and thoroughly mixed with the other ingredients for 3minutes.

CEMENT + SAND + GRANITE
(Mixed for 30 Seconds)
+
WATER + ADMIXTURE
(Mixed for 3 minutes)
↓
CONCRETE

2.3 DETAILS OF CONCRETE CUBE CAST

In this research, a total of 90 cubes of 15x15x15cm mould were cast. With 18 control sample cubes for conventional concrete mixing and 36 cubes each for the two-phase concrete mixing (cement paste and Grout), making up a total of 90 cubes. 15 batches of mix were produced, with each containing 6 cubes per batch. After the casting process, the concrete mould is properly vibrated until the cement paste appeared on the surface of the samples, Polish standard PN 88/B-06250.

Table 2.2: Types of Concrete Mixes and Test Ages

Concrete Mixing Method	Water/ cement	Curing Time (Days)	Mix speed	Sample average	No. of cubes to cast
Conventional Mixing (Control sample) + Superplasticizer	0.40,/ 0.45,/ 0.50 (x3cubes)	7 & 28 (x3cubes)	Slow speed (x1cube)	X3 cubes	**18 cubes**
Cement Paste + Aggregate + Superplasticizer	0.40,/ 0.45,/ 0.50 (x3cubes)	7 &28 (x3cubes)	Slow & high-speed (x2cubes)	x3 cubes	**36 cubes**
Grout + Coarse Aggregate + Superplasticizer	0.40,/ 0.45,/ 0.50 (x3cubes)	7 &28 (x3cubes)	Slow & high-speed (x2cubes)	x3 cubes	**36 cubes**
Grand total no. of cubes cast					**90cubes**

3.0 RESULTS AND DISCUSSION

3.1 RESULTS SUMMARY

GRADING ANALYSIS OF AGGREGATES

The result of the sieve analysis and grading curves of sand and granite are presented in Figure3.1. The particle sizes on sharp sand shows fine aggregate of 98.78% passing through the 4.75mm aperture, 26.25% passing through the 425microns aperture, 16.93% passing through the 300microns aperture, 3.05% passing through the 150microns aperture and finally, 0.63% passing through the 75microns aperture. The coefficient of uniformity (Cu) was found to be 1.87 while the coefficient of gradation (Cc) was 0.31.

The result of the sieve analysis on granite stone shows coarse aggregate of 100% passing through 24mm aperture, 97.09% passing through the 19.50mm aperture, 36.55% passing through the 14mm aperture, 2% passing through the 10mm aperture, and none passing through the 6.30mm aperture.

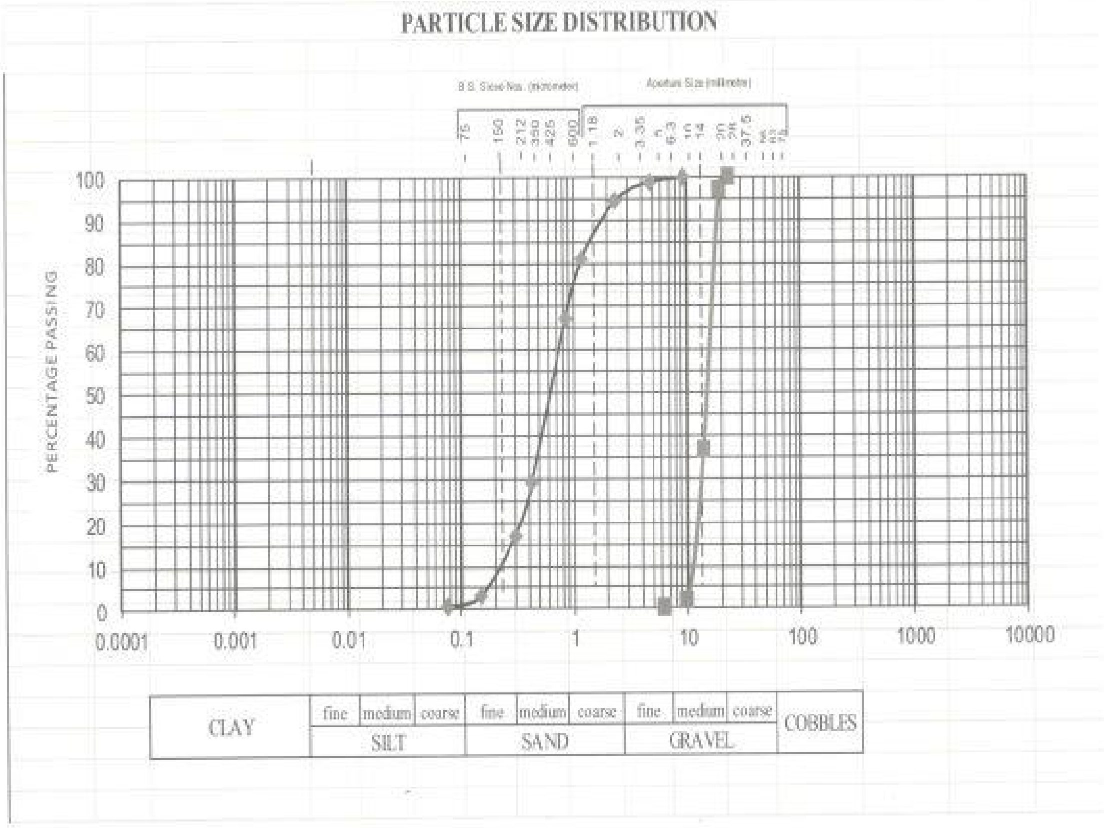

Figure 3.1: Particle Size Distribution Graph

COMPRESSIVE STRENGTH RESULT OF TWO-PHASE Vs. NORMAL CONCRETE

Below is a summary of the result obtained on the compressive strength of concrete made from Two-Phase mixing method in comparison with control sample. The test results for all cement paste, grout and control sample are presented in Tables 3.1 to 3.4 and it is also represented graphically in Figs 3.2 to 3.6

Table 3.1: Compressive Strength Result of Two-Phase Vs. Normal Method A

CONCRETE MIXING METHOD	WATER-CEMENT RATIO	SLUMP (MM)	COMPRESSIVE STRENGTH (N/MM^2)	CURING DAYS
NORMAL MIXING OF CONCRETE	0.40	75	**23.41**	7 DAYS
	0.45	95	**22.89**	
	0.50	135	**20.52**	
TWO-PHASE PRE-	0.40	95	**31.36**	

MIXING OF CEMENT	0.45	155	**29.85**	
	0.50	245	**17.44**	
TWO-PHASE PRE-MIXING OF GROUT	0.40	105	**24.00**	
	0.45	175	**17.41**	
	0.50	245	**16.30**	

Table 3.2: Compressive Strength Result of Two-Phase Vs. Normal Method B

CONCRETE MIXING METHOD	WATER-CEMENT RATIO	SLUMP (MM)	COMPRESSIVE STRENGTH (N/MM^2)	CURING DAYS
NORMAL MIXING OF CONCRETE	0.40	75	**27.71**	28 DAYS
	0.45	95	**24.44**	
	0.50	135	**23.04**	
TWO-PHASE PRE-MIXING OF CEMENT	0.40	95	**33.78**	
	0.45	155	**28.96**	
	0.50	245	**24.60**	
TWO-PHASE PRE-MIXING OF GROUT	0.40	105	**28.00**	
	0.45	175	**23.33**	
	0.50	245	**19.19**	

Table 3.3: Effects of Mix-Speed on Compressive Strength of Cement Paste Concrete

MIXING METHOD	CURING DAYS/ MIX SPEED	WATER-CEMENT RATIO	SLUMP (MM)	COMPRESSIVE STRENGTH (N/MM^2)
PRE-MIXING OF CEMENT	25 RPM OF 28 DAYS	0.40	105	**29.11**
		0.45	175	**26.15**
		0.50	245	**16.84**
	32 RPM OF 28 DAYS	0.40	95	**33.78**
		0.45	155	**28.96**
		0.50	245	**24.60**

Table 3.4: Effects of Mix-Speed on Compressive Strength of Grout Mix concrete

MIXING METHOD	CURING DAYS/ MIX SPEED	WATER-CEMENT RATIO	SLUMP (MM)	COMPRESSIVE STRENGTH (N/MM^2)
PRE-MIXING OF GROUT	25 RPM OF 28 DAYS	0.40	115	**23.41**
		0.45	220	**18.82**
		0.50	250	**17.18**
	32 RPM OF 28 DAYS	0.40	85	**28.00**
		0.45	140	**23.33**
		0.50	225	**19.19**

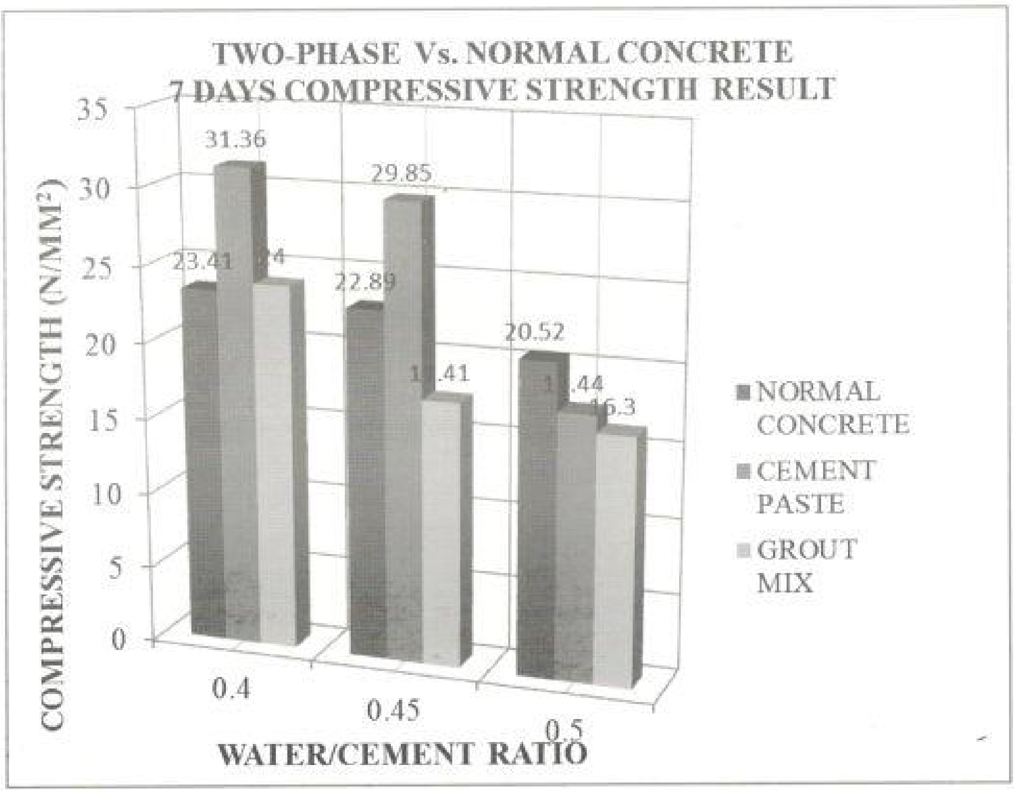

Figure 3.2: 7 Days Compressive Strength Result of Two-Phase Vs. Normal

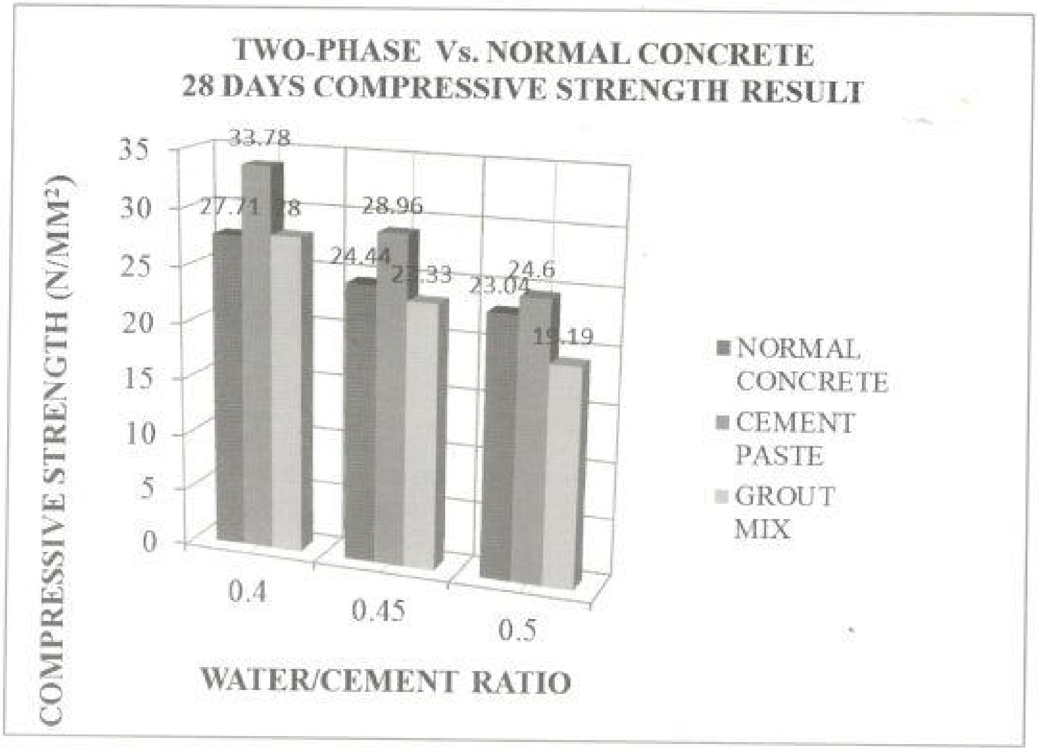

Figure 3.3: 28 Days Compressive Strength Result of Two-Phase Vs. Normal

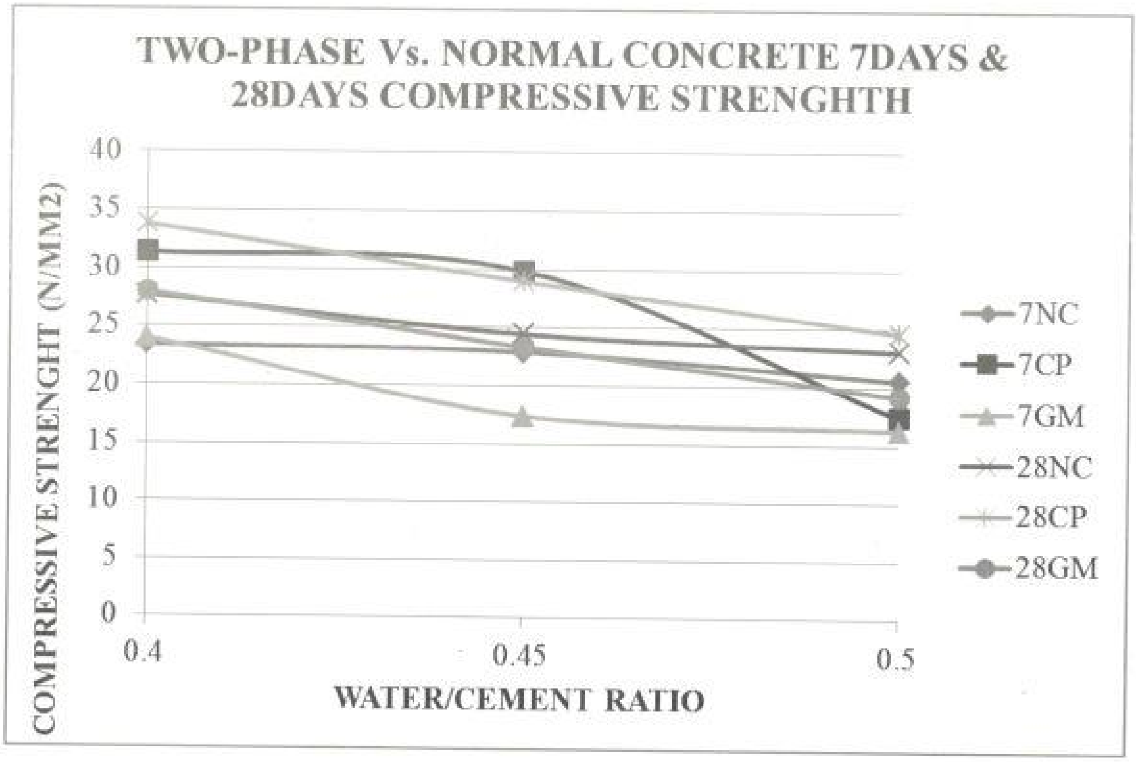

Figure3.4: 7&28 Days Compressive Strength Result of Two-Phase Vs. Normal *7NC = 7 days normal concrete *7CP = 7 days cement paste concrete *7GM = 7days grout mix concrete *28NC = 28 days normal con crete *28CP = 28 days cement paste conc. *28GM = 28 days grout mix conc.

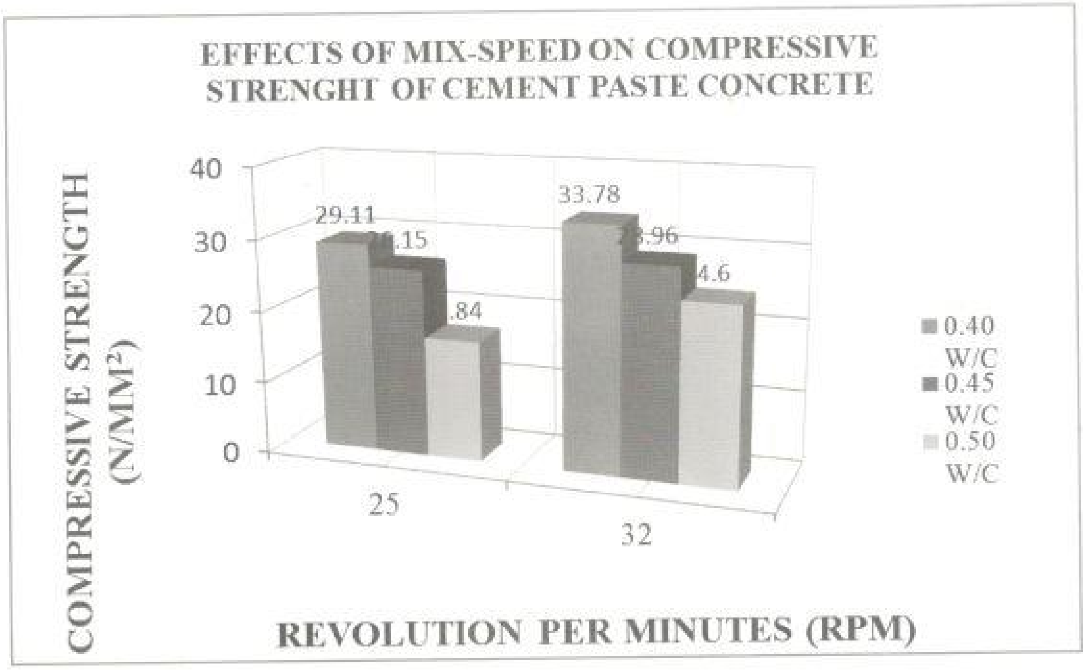

Figure 3.5: Effects of mix-Speed on Compressive Strength of Cement Paste Concrete

*W/C = water/cement ratio

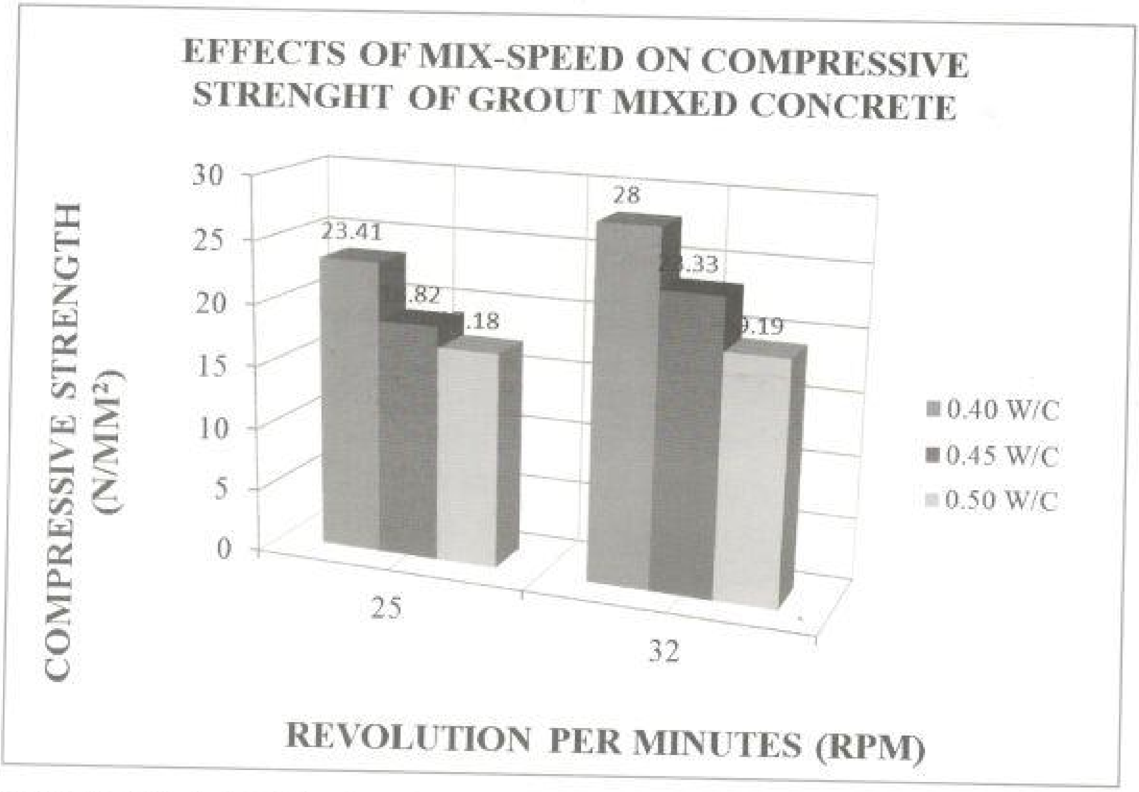

Figure 3.6: Effects of mix-Speed on Compressive Strength of grout mixed concrete

*W/C = water/cement ratio

3.2 DISCUSSION

Grading Analysis of Aggregates: The results show that majority of the grain sizes for granite are largely between 24mm< and ≥19mm. While that of fine sand is between 850μ and 150μ (micron aperture). The implication of this analysis on the sieve test, as also indicated on the conventional semi-logarithmic plot (Figure 3.1), shows that the particle distribution for both fine and coarse aggregates are well graded and suitable for the purposed of this project.

Slump Test: The property of fresh concrete (i.e. concrete at its green state) is very crucial to the quality and strength of concrete at its dense state to a large extent. Therefore, slump test basically determines the rate of workability, consistency in flow and water content in fresh concrete. In achieving these qualities mentioned earlier, slump test was conducted and the results are shown in Tables 3.1 to 3.4. Slump result indicates a low/true slump for concretes with 0.40 water/cement ratio and a high/share slump for concretes with 0.45 water/cement ratio and a near collapse slump for concretes with 0.50 water/cement ratio.

Generally, the slump test indicates a highly workable concrete and this was achieved despite the low water/cement ratio due to the addition of superplasticizer. The result further indicates that the two-phase concrete has a higher slump values compared to the control. This may be as a result of mixing energy and the phases at which water is added.

Compressive Strength Result: A careful examination and analysis of results obtained from the compressive strength test conducted on the three categories of concrete samples (Normal, Cement Paste and Grout Mix concretes) are tabulated in Tables 3.1 to 3.4 and presented on graphs in Figure 3.2 to 3.6. The results for 7 days compressive strength shows an average of 20.52N/mm^2 to 23.41N/mm^2 for Normal concrete, 17.44N/mm^2 to 31.36 N/mm^{2}for cement paste and 16.30N/mm^2 to 24.60 N/mm^2 for grout mix concrete as in Table 3.1.

While results for 28 days show an average of 23.04 to 27.71N/mm^2 strength for Control concrete, 24.60n/mm^2 to 33.78N/mm^2 for Cement Paste and 19.19N/mm^2 to 28.00N/mm^2 for grout mix concrete. The result generally shows an upward increase in compressive strength as water/cement ratio decrease as in Tables 3.1 and 3.4

Comparing the three categories of concrete samples investigated during this project (Control, Cement paste and Grout mix), results show that concrete made by the Two-Phase method particularly that of the Cement paste concrete has indicated the highest record of compressive strength in both 7 and 28 days, as in Figures 3.2 to 3.6. Records also show that there is an average of 21.9% increase in compressive strength of Two-phase method over the Control concrete. After 28days of curing and crushing, Cement Paste concrete has the highest compressive strength with 33.78N/mm^2 which represents 21.9% increase over that of Control concrete with 27.71N/mm^2 for 0.40 water/cement ratio. While Grout mixing method only managed a 1.05% increase with 28.00N/mm^2.

As water/cement ratio increases, concrete made from Two-phase particularly, the grout mixed concrete shows an abrupt steady decline in strength while that of Normal concrete has a gradual and slight decline in compressive strength, as in Figures 3.2 and 3.3.

Figures 3.5 and 3.6 clearly show the effect of Mixing Speed on concrete made from Two-phase. The results show that the higher the mixing speed the better the homogeneity in the paste mix and aggregate coating with cement paste or grout. This therefore affects the strength as it shows an increase in strength when there is increase in mixing speed.

4.0 CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

The following conclusions can be derived:

1 Two-phase premixing method of concrete has a significant effect on the compressive strength of concrete.

2 The compressive strength of "Two-phase" concrete increased by 21.9% at 28 days of curing over the control sample in the experiment, i.e. the "Normal" concrete.

3 Premixing of Cement Paste concrete has the highest compressive strength with 33.78N/mm^2 which represents 21.9% increase over that of Normal mixed concrete with 27.71N/mm^2 for 0.40 water/cement ratio. While Grout mixing method only managed a 1.05% increase with 28.00N/mm^2.

4 Mixing-speed has a significant effect on the compressive strength of Two-phase concrete. Results have shown that cement paste concrete mixed at 32 RPM has a 16% increase in strength over same mixed at 25 RPM. And for grout mix concrete, percentage increase recorded was 19%.

5 The result also confirms the effect of water/cement ratio on strength of concrete. Thus the higher the water/cement ratio, the weaker the strength of concrete.

6 With the addition of 2% volume of superplasticizer in the mix design for all concretes, adequate workability was achieved, whilst a very low water/cement ratio was maintained.

4.2 RECOMMENDATION

The project should be repeated by employing a faster ultra-mixing drum of about 3000 rpm, as this eventually will improve on the findings already established.

More findings should be done in the area of Effective Mixing Time; as this, has also been noted to have an effect on the properties of the concrete.

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