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Evaluation of the Properties of Air Entrained Concrete at Moderate Water-Cement Ratio

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ABSTRACT : *This work investigated the use of air entraining agents in concrete as a way of proposing a suitable dosage required for structural concrete. A special type of air entraining agent (costamix c) was used in the study. Laboratory tests were carried out on the concrete samples; slump test and compressive strength tests. The slump tests were to measure the workability of concrete carried out using slump cones, base plates, tamping rod, sample scoops, slump cone filling and a measuring device in accordance with the standard procedure while, the compressive strength tests involved mixing of the constituents; cement, sand, coarse aggregates, air entraining agent and water at at moderate water-cement ratio of 0.6 and casting of the concrete cubes on moulds of 150 x 150 x 150 mm. The cubes were demoulded after 24 hours and cured in water after which testing for the strength using the concrete compression machine was done after 7, 21 and 28 days respectively. The result of the slump test was 30mm for specimen without air entraining agents as against 70mm for those with 1.0% air entraining agent indicating increase in workability with the presence of air entraining agent. While the compressive strength for all levels of addition of air-entrainers, there was increase in the 7-days compressive strength but reduction in the 28 days strength but the most advantageous compressive strength with air entrainer was obtained at 0.9% for the various days; the 28-day compressive strength being 21.44 N/mm^2 at that level of addition.*

KEYWORDS: *water-cement ratio, workability, air entrained, concrete, compressive strength*

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I. INTRODUCTION

Cementitious materials, aggregate, water, and chemical admixtures in the right proportion are the major constituents of concrete, which is used in building. Concrete has been widely used in various buildings and infrastructure worldwide. However, like a typical porous medium, concrete is generally prone to deterioration under extreme climatic conditions. Concrete, for example, is vulnerable to freeze-thaw damage in cold regions because of water invasion. To reduce the freeze–thaw deterioration, the most commonly adopted method in the world is to use air-entrained concrete according to the theoretical hypothesis that the purposely introduced air voids can provide extra space to decrease expansion pressure induced by freezing water (Zhang, 2018, and Wang , 2022). A variety of test procedures have been used to determine the air void system of concrete. For fresh concrete, some standard tests include the (BS-1881-106) pressure method, (BS 1881- 114) gravimetric method, and (BS 1881- 107, 1983) volumetric method. Because of its ease of use and practicality on the construction site, the pressure method is the one most frequently employed in the concrete industry for quality assurance and control. While the aforementioned test methods offer numerous benefits, their efficacy is also impacted by certain limits. For instance, the measured air content of fresh concrete cannot characterize the spacing of air voids, which is more critical to improving the freeze–thaw resistance. It has been widely noted that while some freshly mixed concrete satisfies agency-specified air content requirements, the (BS EN 772-22 2018) freeze-thaw test, indicated that the corresponding hardened concrete was not freeze–thaw-durable (Freeman, 2012, Ashraf, 2018). It is possible to measure the air void distribution parameters for hardened concrete, such as the spacing factor using (BS EN 480-11 2005), although this is a laborious and time-consuming test. In addition, much faster and more convenient test methods such as image processing (Jakobsen 2006) ultrasonic scattering measurement (Guo, 2017), X-ray CT, 2D to 3D unfolding techniques (Song Y. 2021), macro-photography (Suárez 2018), and the photometric stereo method (Tao, 2021) have been developed to obtain the air void distribution in hardened concrete. Reduced water to cement ratios (w/c) are possible because air entrainment makes concrete more workable. Greater impermeability and overall resistance to aggressive agents are seen in concrete with improved compaction properties and lower water-to-cement ratios. There is thus, the need to investigate the effectiveness, advantages, disadvantages of Air Entraining Agents (AEA) in concrete production. Nowadays, concrete may be utilized for a wide range of applications to fit various situations. Ordinary concrete may not perform as expected in terms of quality and durability under these circumstances. Admixtures are utilized in certain situations to change the characteristics of regular concrete, making it more adaptable to different circumstances. The development of air-entrained concrete is considered one of the major advances in concrete technology. A little amount of air-entraining chemical can be combined with air-entraining cement to generate air-entrained concrete. Millions of non- coalescing air bubbles function as flexible ball bearings in these air-entraining chemicals, changing the workability, segregation, bleeding, and finishing quality of concrete. It also modifies the properties of hardened concrete, including its permeability and susceptibility to frost action. By decreasing the overall porosity and raising the unit weight of the pervious concrete, air entrainment improves workability. Excellent workability, good strength and abrasion resistance, minimal permeability, and enhanced chemical resistance were some of the results of using air-entraining admixtures. The addition of dry super absorbent polymers (SAP) for air entrainment in concrete is beneficial for frost protection of concrete (Laustsen, 2008). In circumstances where concrete structures are liable to freezing and thawing, concrete durability can be further enhanced through uniform entrainment of air bubbles of optimal dimensions and total volume (Arum, 2006).

The air void system's parameters were interpreted using the symbols and terminology in accordance with (BS EN 480-11 2005)

The air content of concrete is composed of entrained and entrapped air voids. Entrained air is defined as small air bubbles that are purposely integrated into concrete during mixing, typically with a surface-active chemical. These bubbles are spherical, with dimensions ranging from 0.0004 to 0.04 in. (0.01 to 1 mm). Entrapped air voids, on the other hand, are found in all concrete, are irregular in shape, and are often larger than 0.04 in. (1 mm), making them less useful than entrained air voids. Because the bubbles are smaller and more evenly distributed, entrained air shortens the distance that water must travel through the capillary pores before entering a microscopic vacuum to expand and release pressure. (Hover, 2001)

Many variables greatly affect the size distribution and frequency of the air void system in an unhardened, air-entrained concrete, and consequently, the hardened concrete's resistance to frost**.** They include proprieties of the air entraining agent, water - cement ratio and properties of the solids in the concrete mix.

Air Entraining in Concrete affect the physical and mechanical properties of concrete. Because of the air bubbles that lubricates the particles and lessen the need for water and sand, the cement here has a high workability rating. Since the strength and w/c ratios are inversely related. Greater strength is indicated by a smaller w/c ratio. The w/c ratio is kept low by using air-entrainer, and so the strength parameter of the concrete is not compromised. However, it is hard to achieve high-level strength concrete with air-entrained cement. The low temperature in the chilly environment causes the water inside the concrete to freeze and expand. By using this concrete, the water is given the space it needs to expand, preventing the concrete from cracking. But the enhanced water is contained by entrained air bubbles, which lowers expansion pressure and prevents concrete damage. Because the w/c ratio may be kept low, which initiates the sulfate attack, the air-entrained concrete has a strong ability to survive sulphate attack. The permeability of air-entrained concrete is larger than that of non-air-entrained concrete because air bubbles break the capillaries. Hence, the use of air-entrained concrete where water tightness is required is encouraged.

Some of the disadvantages of air entrained concrete include reduction of the strength of concrete, concrete's porosity can be increased using an air entraining agent, which lowers the unit weight. Air-entrainment in concrete should not be performed if the site control is not superior because the air entrained in a concrete differs with the alteration in sand grading, errors in proportioning and workability of the mix and temperatures. When the water-to-cement ratio rises for a certain concrete mixture, the air content rises and the bubbles' specific surface area falls. As pointed out by Powers (Powers, 1964) air presumably enters concrete as a result of the unfolding action of the fluid mixture. The unfolding movement is restricted to the area around the mixing source as the fluid mixture stiffens, with the remaining mixture remaining silent. Consequently, less air is entrained the stiffer the mix (lower the water-cement ratio). The enhanced water cement ratio results in a lower specific surface area of the air void system, which is caused by low shear stress in the fluid material. Powers has pointed out that more viscous materials (low water-cement ratio) have larger shear stresses, allowing for the separation of smaller bubbles than would otherwise occur. In contrast, a high water-cement ratio results in a more fluid material with low shear stresses that cannot divide the larger bubbles. This produces a void system with a low specific surface area.

The Effects of increased water-cement ratio on air entrained concrete include a reduction in the specific surface area of the air void system; increased air content of the cement paste; increases in the fraction of big voids while a decrease in the overall number of voids . Finally the water cement ratio 0.6 is typical for mix that prioritizes ease of placement. While higher water content can reduce the final strength of concrete, this is balanced out by the introduction of air entraining agent.

II. MATERIALS AND METHODS

2.1. Materials

The materials employed in this study include

a. CostarMix C AIR

Fig 2.1: A photo of Air Entraining Agent used (Costarchem Nigeria 2024)

b. Ordinary Portland Cement: Dangote Portland Cement of 42.5N grade.

c. Aggregates (Coarse of 19mm maximum size and Fine): Components in granular form smaller than 4.75mm are known as fine aggregates, while those larger than 4.75mm are referred to as coarse aggregates.

d. Potable Water from borehole

2.2. Methods

The Following were carried out in the course of this study was carried.

1) Materials were collected and Tests to obtain their physical properties
2) Trials on different % of Costarmix C (Air entraining agent) in concrete cube was done

3) The Workability of the different samples of air entrained mortar were tested for workability
4) Finally the Compressive strength of the hardened air entrained concrete was found at 7, 21 and 28 days

2.2.1. Procedures employed in the Slump Test

For every batch of mixed concrete, the following steps were carried out. The internal surface of the mould were cleaned and grease applied. The molds were placed on a smooth horizontal non porous base plate. The mold were filled with the prepared concrete mix in three approximately equal layers. The tamping rod was used to tamp the concrete 25 times for each layer. The excess concrete was removed and the surface leveled with a trowel. The mold was raised from the concrete in a vertical, the concrete subsided. The vertical distance between the top of the mold and the displace center of the top of the specimen was measured as the slump value.

.2.2.2. Compressive Strength Test

To find the compressive strength and other general properties of concrete, concrete cube tests are carried out. Concrete cubes are crushed in a compression testing machine as part of this destructive testing technique. As long as the largest aggregate is no larger than 20 mm, the test's cubes are 150 x 150 x 150 mm. After the concrete is first poured into the mold, any holes or cavities are filled in by tempering. After 24 hours, the specimens are taken out of the molds and placed in curing tank until they have undergone the necessary curing times as specified in the project specifications. The specimen surfaces are evened out and polished after curing. The sample is then gradually subjected to a force of 140 kg/cm^2 using a compression testing equipment until it fails, this determines the tested concrete's compressive strength.

The following is the formula for the concrete cube test, which measures the compressive strength of any material:

Compressive Strength = Load / Cross-sectional Area

It is Mathematically represented as

$$Fc = \frac{P}{A} \text{.....................Eqn 2.1}$$

Where, A is the cross sectional area of the test cubes in square meters (m^2)

P= failure load in KiloNewton (kN).

Thus, it is the load applied to the cross-sectional area on the face to which the load was applied at the moment of failure

III. RESULTS AND DISCUSSION

The results for the experimental works are presented .

3.1 Slump Test Results

The result of the slump test is shown in Tables 3.1 to 3.3. The materials are proportioned in a 1:3:6 ratio (cement: fine aggregate: coarse aggregate). The slump test measure the workability or consistency of fresh concrete. From Table 3.1, the value of 30mm for the concrete without air entrainer indicates a low workability. This level of slump suggests that the mix is relatively stiff and would be more challenging to handle and place in intricate forms or tights spaces.

Table 3.1: Result of Slump Test for concrete content without Air Entraining Agent

MATERIALS	Wt (kg)
Cement	6
Fine Aggregates	12
Coarse Aggregates	24
Water	3.6kg
Slump Test	30mm

The slump test result shown in Table 3.2 for 1.0% addition of air entrainer, the slump value of 70mm indicates a medium workability. This indicates that the addition of air entrainer at 1 percent is capable of causing an increase in the workabilty of concrete to the tune of over 100%. The addition of an air entraining agent at 1% is critical for the durability of the concrete by creating microscopic air bubbles, the concrete becomes more resistant to freeze thaw cycle which can otherwise cause cracking. A 70mm slump indicates moderate to good workability. This slump suggests the mix is fluid enough for easy placement in most construction tasks but is not so wet that it will segregate or lose strength.

Table 3.2: Result of Slump Test For Concrete With 1% Air Entraining Agent

MATERIALS	**Wt (kg)**
Cement	6
Fine Aggregates	12
Coarse Aggregates	24
Water	3.6
Air Entrainer	0.06
Slump Test	70mm

For the slump test result shown in Table 3.3 for 0.9% addition of air entrainer, the slump value of 65mm indicates a medium workability. This indicates that the addition of air entrainer at 0.9% is capable of causing an increase in the workabilty of concrete to the tune of over 100%.

Table 3.3: Result of Slump Test For Concrete With 0.9% Air Entraining Agent

MATERIALS	Wt (kg)
Cement	6
Fine Aggregates	12
Coarse Aggregates	24
Water	3.6
Air Entrainer	0.054
Slump Test	65mm

For the slump test result shown in Table 3.4 for 0.8% addition of air entrainer, the slump value of 60mm indicates a medium workability. This indicates that the addition of air entrainer at 0.8% is capable of causing an increase in the workabilty of concrete to the tune of 100%.

Table 3.4: Result of Slump Test For Concrete With 0.8% Air Entraining Agent

MATERIALS	**Wt (kg)**
Cement	6
Fine Aggregates	12
Coarse Aggregates	24
Water	3.6
Air Entrainer	0.048
Slump Test	55mm

2.2 Results for Compressive Strength Tests.

The result of the compressive strength of the concrete for the various days are shown in Table 3.5. The 7 days test results showed that for all the percentage addition of air entrainer, there was increase in the compressive strength as compared with the control of 12.21 N/mm^2. The highest compressive strength was obtained as 14.12 N/mm^2 at 0.9% addition of air entrainer indicating a 15.56% increase at the level while the lowest compressive strength was obtained as 13.3 N/mm^2 at 1.0% addition of air entrainer indicating an increase of 8.93%.

The 21 days test results showed that for all the percentage addition of air entrainer, there was decrease in the compressive strength as compared with the control of 17.23 N/mm^2. The highest compressive strength with air entrainer was obtained as 16.12 N/mm^2 at 0.9% addition of air entrainer indicating a 6.44% reduction from the control while

the lowest compressive strength was obtained at 1.0% addition of air entrainer with a 7.7% decrease from the control.
The 28 days test results without the use of air entrainers gave a compressive strength of 22.11 N/mm^2. With the addition of air entrainers at the three levels, there was decrease in the compressive strength. At 0.8%, a compressive strength of 20.5 N/mm^2 was obtained indicating a 7.28% decrease. At 0.9%, a compressive strength of 21.44 N/mm^2 was obtained indicating a 3.03% decrease from the control. While at 1.0%, a compressive strength of 19.02 N/mm^2 was obtained indicating a 13.9% decrease from the control. This tallies with previous work that addition of air entrainers reduces the long term compressive strength of concrete.

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Table 3.5: Result of Compressive Strength Test for concrete

S/N	%age of Air Entrainer	Compressive Strength at 7 Days (N/mm^2)	Compressive Strength at 21 Days (N/mm^2)	Compressive Strength at 28 Days (N/mm^2)
1	0	12.21	17.23	22.11
2	1.0	13.3	15.9	19.03
3	0.9	14.12	16.12	21.44
4	0.8	13.4	15.93	20.5

IV. CONCLUSION AND RECOMMENDATION

4.0. CONCLUSION

The effects of air entraining agents on the cement, aggregates, and water content of a freshly mixed concrete mix have been investigated. It was observed that the air bubbles created by the use of air entraining agents dispersed throughout the concrete's bulk and functioned as flexible ball bearings. These pliable balls also function as fine aggregates, resulting in a decrease in aggregates and a subsequent decrease in cement and water content. The following are conclusions are derived so far:

1. Increase in the volume of air entrainers results in increase in the workaility of concrete for the various levels considered with the highest workability achieved at 1.0% addition of air entrainer.

2. Air entrainer agent impacts on the compressive strength on concrete positively for short term period and negatively for long term periods thus a suitable level of its addition should be determined bearing in mind the overall expected outcome.

4.1. RECOMMENDATIONS

Based on these tests carried out, the following are recommendations made:

1. Investigate other factors that affects the properties of Air Entrained Concrete.

2. Investigate other water-cement ratio and other doses of Air Entrainers in Concrete.

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