Structural Use of Low Dosage Waste Paper Ash In concrete

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Abstract: **After use, paper often becomes waste, contributing to environmental issues through incineration or littering. This study explores the potential use of discarded paper as a partial substitute for cement, ranging from 0% to 15% in 5% increments. Concrete cubes were prepared for each substitution level following a mix design ratio of 1:2:4 and a water-cement ratio of 0.5, undergoing curing for 7, 14, 21, and 28 days. Assessment included predictive tests for strengths, workability, consistency, water absorption, and compressive strength, adhering to British Standard specifications and mathematical models. Results showed a well-graded aggregate size distribution and true slumps in fresh concrete. Waste paper ash (WPA) and cement had specific gravities of 3.13 each, with mixtures ranging from 3.12 to 3.15 for WPA content from 5% to 15%. Notably, 15% WPA exhibited the highest water absorption (3.06%), while 0% had the lowest (2.30%). Compressive strengths at 28 days for altered concrete (5-15% WPA) ranged from 15.32 N/mm² to 27.71 N/mm² compared to 25.56 N/mm² for the control. Strength loss followed a similar trend across compressive, flexural, and split strengths. The modulus of elasticity ranged from 25 to 29.58 GPa, with Poisson's ratio from 0.31 to 0.41. These findings suggest that within the experimental context, waste paper ash demonstrates properties akin to conventional Portland cement when substituted.**

Keywords: **cement, concrete, waste paper ash, recyclable, replacement.**

I. INTRODUCTION

Concrete is renowned for its versatility and widespread use in the construction industry, comprising aggregates, cement, and water, often with admixtures. The strength and durability of concrete depend on precise concreting processes, including proportioning, blending, and compaction during placement. The demand for concrete has surged due to rapid urbanization and population growth in developing countries, driving infrastructure and housing development. However, cement, a key component of concrete, poses environmental challenges and carries a significant energy cost. According to Meko (2020), the production of Ordinary Portland Cement (OPC) contributes to about 2.4% of global carbon dioxide emissions, highlighting the need for sustainable alternatives in construction materials. The escalating demand for cost-effective and eco-friendly alternatives has spurred the investigation of supplementary cementing materials for concrete production. Substituting cement with various materials has become a widespread practice in the construction industry. Presently, a multitude of supplementary pozzolanic materials are being utilized to partially replace cement. These materials encompass a wide range, including waste paper ash, fly ash, waste glass, pumice, paper pulp, silica fume, sugarcane bagasse ash, ceramic waste, glass powder, recycled tire aggregates, rice husk ash, eggshell, blast furnace slag, and others.

Pera and Amrouz (2003) discovered that calcined paper sludge, when combined with calcite and metakaoline at 650°C, can effectively replace up to 20% of ordinary Portland cement in concrete. Interestingly, this mixture exhibited a rapid consumption of hydroxide compared to pure metakaoline, resulting in concrete with reduced pore size and enhanced compressive strength. On the other hand, Gallardo and Andajar (2006) investigated the feasibility of incorporating paper mill sludge as a partial replacement for fine aggregates in fresh concrete production, particularly for low-cost housing projects. The findings revealed that sludge presents a feasible alternative, particularly when used in the range of 5-10% of fine aggregates, as higher percentages led to a decline in both tensile and compressive strength. This reduction in strength was attributed to the paper's high water absorption and the absence of silver compounds, which aid in drying water within the sludge (Jayeshkumar et al., 2013). Moreover, Jayeshkumar et al. (2013) examined the characteristics of paper ash and observed that replacing cement with paper ash resulted in decreased compressive strength. However, as the proportion of paper ash increased, there was a corresponding rise in compressive strength, albeit with decreases in tensile strength. This suggests that paper ash holds promise as an innovative additional cementitious material in the construction sector. Abdullah et al. (2014) conducted experiments to assess how substituting cement with paper waste affects the structural performance of concrete. They found that in M20 and M30 concrete grades, the tensile strength increased when hypo sludge replaced 10% of the cement compared to conventional concrete. With a 20% substitution, the strength matched that of conventional concrete, but it decreased at 30% substitution. In another study, Nazar et al. (2015) aimed to ensure that concrete made with paper mill sludge had adequate mechanical strength. They evaluated properties like compressive strength, flexural strength, ultra pulse velocity, and dynamic modulus elasticity in concrete mixes containing 10%, 20%, and 30% paper mill waste. The strength of these mixes was compared to a control mix, revealing an inverse relationship between concrete strength and paper mill waste content. Additionally, they observed a strong correlation between density and concrete strength when incorporating paper mill sludge. The study seeks to explore the impact of replacing cement binder with waste disposal papers in concrete production, focusing on various physical properties such as workability, consistency, setting time, and compressive strength. Its objective is to assess the outcomes of substituting cement binder with waste disposal papers in concrete production. This research aims to evaluate key physical parameters including workability (effectiveness), consistency (uniformity), setting time, and compressive strength to understand the implications of this substitution.

II. METHODOLOGY

In this experimental study, waste papers sourced from a cybercafé, known for extensive paper usage, were collected and processed. The papers were shredded into smaller fragments and subsequently incinerated at a temperature of 550°C using a furnace. The resulting ash from the incineration process was then sieved to ensure it met the particle size requirements outlined in BS 882:1992, specifically passing through a 50-mesh sieve. This prepared paper ash was then utilized to partially replace ordinary Portland cement (OPC) in concrete mixtures. Additionally, geochemical analysis was conducted using X-Ray Fluorescence (XRF) to determine the chemical composition of oxides present in the waste paper ash. All concrete mixtures were prepared using commercially available Portland cement obtained from Elephant Portland Cement Company, which adheres to the specifications outlined in BS 12:1996 for Portland cement.

Coarse aggregates, having a maximum size of 19mm, and fine aggregates were sourced from Ilaro, Ogun state. Cement was procured from a Dangote cement retail outlet in Ilaro as well. Portable water from the Material Testing Laboratory of the Federal Polytechnic Ilaro was utilized in the experiments. Sieve analysis was conducted on both coarse and fine aggregate sizes to ensure compliance with specifications. Subsequently, paper waste was substituted at varying percentages (0%, 5%, 10%, and 15%) for cement. A total of seventy-two (72) cubes were cast using a mix design ratio of 1:2:4 with a water-cement ratio of 0.5. These cubes underwent curing in water for durations of 7, 14, 21, and 28 days, following which they were subjected to crushing tests. Engineering tests on the specimens were conducted in accordance with British European Standards. Figure 1 illustrates the process of waste paper collection from a café and dump site at the Federal Polytechnic, Ilaro, Ogun state.

Figure 1: Waste paper and Waste paper ash.

Table 1: Material batch weight in kilograms with a 0.5 water-to-cement ratio

Materials	0%	5%	10%	15%
Cement	11.00	10.45	9.90	9.35
F.A	22.00	22.00	22.00	22.00
C.A	44.00	44.00	44.00	44.00
WPA	0	0.55	1.10	1.65

Note: F.A = Fine Aggregates, C.A = Coarse Aggregates and W.P.A = Waste Paper Ash

The table above presents the batch weights of materials used in the research project, along with the corresponding percentages for substitutions.

III. RESULTS & DISCUSSIONS

A. Particle Size Distribution

The results of the sieve analysis, performed following BS 1377 standards, for both fine and coarse aggregates are depicted in Figures 2 and 3 below. The coefficient of uniformity (Cu) for fine aggregates falls within the acceptable range of 1 to 3, calculated at 2.13, while the coefficient of curvature (Cc) is within the range of 0.5 to 2, measured at 0.91. Furthermore, the fineness modulus, calculated at 3.59, suggests that the predominant average size lies between 1.15mm and 2. 36mm.The analysis of the coarse aggregate reveals a coefficient of uniformity (Cu) of 1.38, falling below the acceptable limit of 6, while the coefficient of curvature (Cc) is measured at 1.05. Additionally, the fineness modulus is calculated to be 2.66. These results indicate that both the fine and coarse aggregates meet the required criteria for the production of effective concrete.

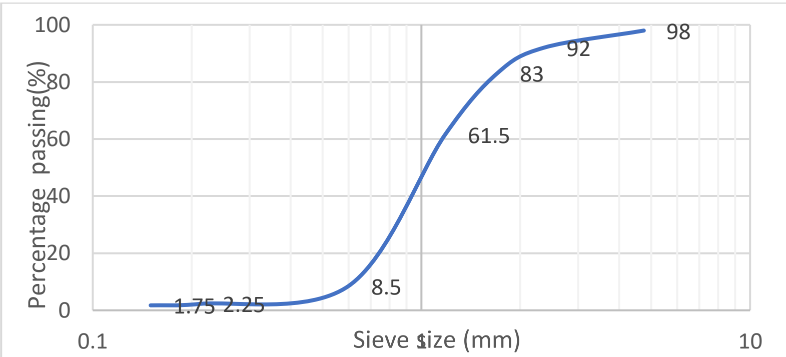


Figure 2: Particle Size distribution curve for fine aggregates

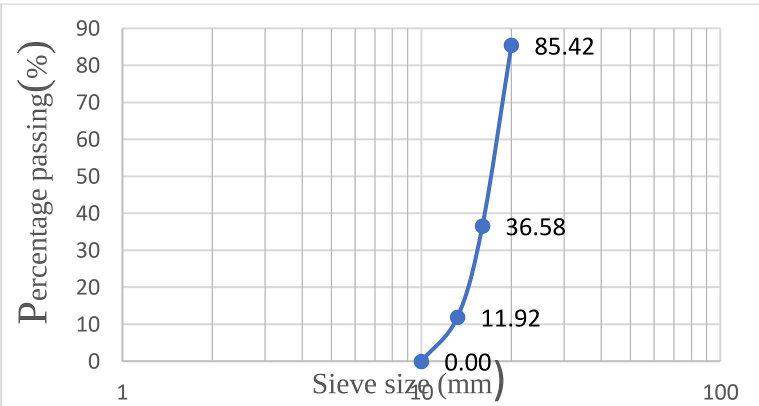


Figure 3: Rough aggregates' particle size distribution curve

B. Specific gravity

Specific gravity is a fundamental property used to assess the suitability of materials for concrete production, indicating their density relative to that of water or another standard substance. This test provides insight into the weight of a material per unit volume, aiding in determining its compatibility and effectiveness in concrete mixtures. By comparing the specific gravity of various materials to established standards, engineers can make informed decisions regarding their inclusion in concrete formulations.

Table 2: Specific gravity of specimen

PERCENTAGE REPLACEMENT	SPECIFIC GRAVITY
100% Cement	3.13
100% WPA	3.10
5% WPA+95% Cement	3.12
10% WPA+90% Cement	3.13
15% WPA+85% Cement	3.15

The data presented in Table 2 illustrates the specific gravity (SG) of conventional cement at 3.13, while the modified variants range from 3.10 to 3.15. This indicates that the modified cement variants used in the study are approximately 3.10 to 3.15 times denser than an equal volume of water, suggesting their sinking in water. Moreover, the specific gravity readings imply that the waste paper ash (WPA) has been meticulously pulverized into a powder form. Interestingly, WPA and ordinary Portland cement (OPC) exhibit nearly identical specific gravity values as shown in Table 3. Additionally, Table 5% indicates a proportional increase in specific gravity as the percentage of WPA rises in the cement modification, indicating that higher WPA proportions lead to increased specific gravity values in the modified cement mixtures.

Consistency Test and Setting Time of Cement Paste

The consistency test aimed to ascertain the water quantity necessary to achieve standard or normal consistency in the cement mixture, following the guidelines outlined in the BS 12 standard description. All measurements obtained during the test fell within the optimal range of 5 to 7 millimeters, ensuring adherence to standard consistency levels.

Table 3: Standard Consistency Test

Vicat apparatus	0%	5%	10%	15%
Needle penetration(mm)	5	5	5.5	6

The initial and final setting time tests for the cement pastes were conducted utilizing Vicat equipment, following the specifications outlined in BS12.

C. Setting time of cement

It was observed that both ordinary Portland cement (OPC) and other modified cement variants displayed initial setting times ranging between 110 and 165 minutes, as detailed in Table 5. Furthermore, conventional cement attained its final setting time at 165 minutes, while all substitute cement mixtures (at 5%, 10%, and 15% replacements) achieved final setting times of 185, 185, and 262 minutes, respectively. These final setting times for all substitute cement mixtures met the standards outlined in BS 12, 1978, and BSEN196-3:1995, indicating satisfactory performance.

Table 4: Cement Paste's Setting time

Sample	Initial Setting Time (min)	Final Setting Time (min)
Cement	110	165
5%WPA+95%Cement	145	185
10%WPA+90%Cement	157	185
15%WPA+85%Cement	165	262

D. Workability

Workability, a crucial characteristic, dictates the ease with which freshly mixed concrete or mortar can be handled, placed, compacted, and finished (ACI, 1990). To assess workability, a slump test was conducted on fresh concrete, adhering to the procedures outlined in BS 1881-102:1983. Figure 4 depicts the results of this test.

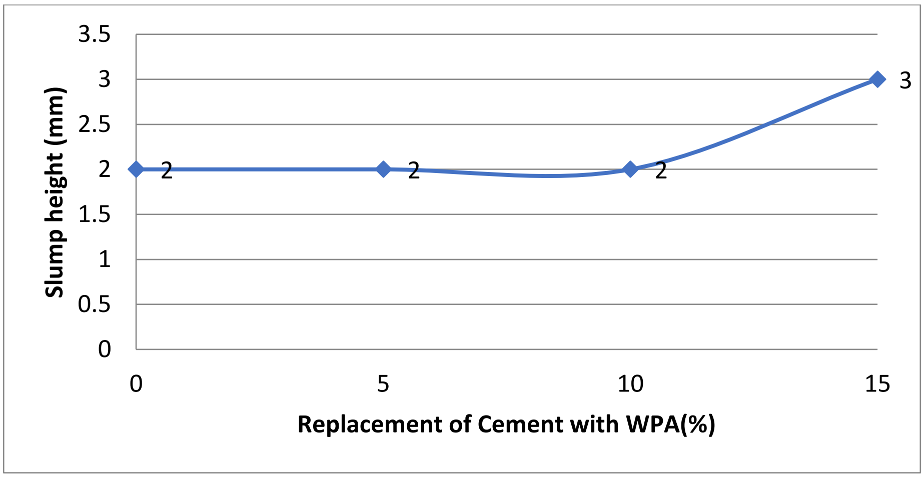


Figure 4: Slump height of conventional concrete and modified concrete with WPA

The observations revealed that at 0% replacement, the slump height measured 2mm, remaining consistent at 5% WPA replacement and 10% replacement. However, it slightly increased to 3mm at 15% replacement. This indicates that the behavior of the modified concrete closely resembled that of the control sample, as both exhibited a true slump within the range of 0 to 25mm

E. Mass Density

Before testing, the weight of each concrete cube was measured to determine its density following the guidelines outlined in BS 1881-114 (1983). Density was calculated by dividing the mass by the volume of each cube, and the results are presented in Table 6 below.

Table 5: Mass Density

Percentage Replacement (%)	Density (Kg/m^3)
0	2331.852
5	2355.556
10	2405.926
15	2441.481

Referring to the data presented in Table 5, the density of the control specimen was recorded at 2331.852 kg/m^3. Upon replacing 5% of the cement with WPA, the density increased to 2355.556 kg/m^3, and further rose to 2405.926 kg/m^3 with a 10% WPA substitution. Subsequently, at a 15% replacement level, the density escalated to 2441.481 kg/m^3. These density values fall within the typical range of 2300 to 2500 kg/m^3 for conventional concrete, indicating their suitability for construction purposes. However, it's worth noting that densities exceeding this range can still serve as cement substitutes, especially up to 4%, considering the similar specific gravity observed for both cement and WPA at these substitution levels, as shown in Table 3.

F. Water Absorption

After demolding, the weight of the cubes was measured following curing periods of 7, 14, 21, and 28 days in water to assess water absorption. This process followed the guidelines outlined in BS 813-2 (1995). The water absorption rate was calculated using the prescribed formula:

Water absorption rate= $\frac{\Delta W}{W_1}$

Where $\Delta W = W_2 - W_1$

$W_1 =$ Weight of cube after demoulding

$W_2 =$ Weight of cube after curing

The results of this calculation are presented in Table 7 below.

Table 6: water absorption from seven to twenty-eight days

Sample replacement (%)	7 days	14 days	21 days	28 days
0	2.30	2.44	2.56	2.72
5	2.62	2.70	2.81	2.91
10	2.75	2.78	2.93	2.98
15	2.84	2.88	3.02	3.06

As shown in Table 7, the water absorption rates for waste paper ash (WPA) after 7 days of curing in water ranged from 2.30% to 2.84% for 0%, 5%, 10%, and 15% WPA replacements, respectively. Similarly, after 14 days, water absorption rates varied from 2.44% to 2.88% for the same replacement percentages. At 21 days, the rates ranged from 2.65% to 3.02%. However, the focus shifted to the 28-day period, where water absorption rates increased slightly from 2.72% to 3.06% as the WPA content in the concrete matrix rose. This rise may be attributed to WPA's reduced ability to retain water compared to cement, leading to increased absorption rates. It's noteworthy that in critical conditions, such as exposure to aggressive chloride or freeze-thaw cycles, water absorption should ideally not exceed 3% or 2%, as per The Maritime Code BS 6349.

G. Compressive Strength

The cubes underwent water curing for durations of 7, 14, 21, and 28 days. After the specified curing period, 150mm x 150mm cubes were tested for compressive strength following the guidelines outlined in BS 1881-116 (1983).

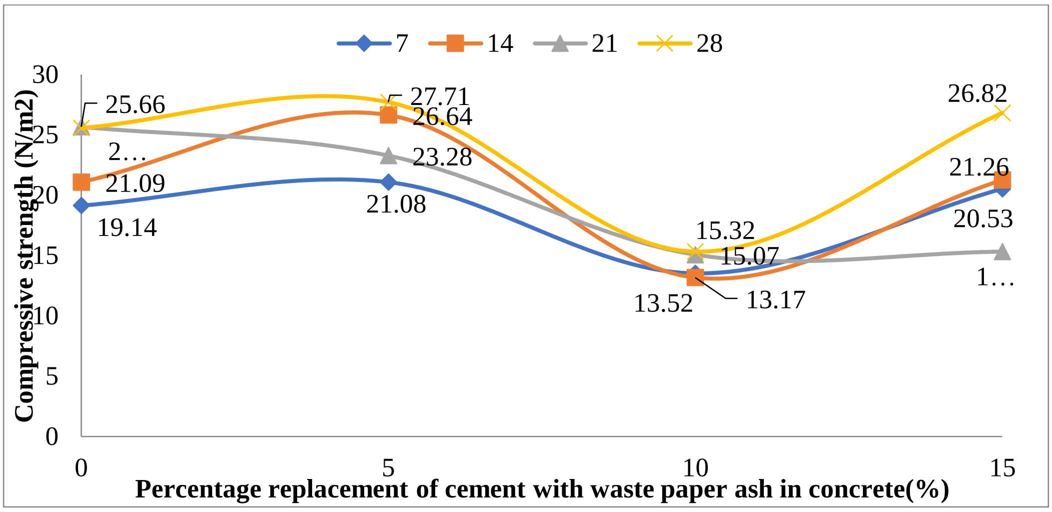


Figure 5: Development of Compressive Strength with curing days

Compressive strength, measured in units of N/mm² or MPa, is calculated as the quotient of the compressive force applied to the cube and its cross-sectional area. The results of the compressive strength test, obtained by substituting waste paper ash (WPA) for cement (binder), are illustrated in Figure 6. Comparing with the control concrete, which exhibited compressive strengths of 19.14, 21.09, 25.66, and 25.56 N/mm² for the corresponding curing periods, it was observed that the highest compressive strength was achieved when 15% of waste paper ash (WPA) was substituted. At 7, 14, 21, and 28 days of curing, compressive strengths of 25.56, 27.71, 15.32, and 26.82 N/mm² respectively were recorded for this sample. These values are notably higher and are considered the most desirable among all samples tested.

H. Modulus of elasticity (E) of concrete modified with paper ash.

Elastic modulus, also known as Young's modulus, refers to the ratio of stress to strain within a material. In conventional concrete, the elastic modulus typically ranges from 14 GPa to 50 GPa.

$E = [(\frac{f_{cm}}{10})]^{0.3}$ (BSEN 1992-1:1) eq 1

Table 7: Modulus of elasticity for concrete modified with waste paper ash at 7,14,21 and 28 days compressive strength.

%	7	14	21	28
0	26.73	27.52	29.15	29.19
5	27.52	29.52	28.35	29.87
10	25	23.89	24.88	25
15	27.3	27.59	25	29.58

The observations reveal a direct correlation between the compressive strength and modulus of elasticity of the modified concrete. This relationship is inherent in the direct proportionality between the modulus of elasticity (E) and compressive strength, as depicted in the equation. Additionally, it's noteworthy that the elastic modulus of the modified concrete aligns with the specified range observed in conventional concrete Poisson's ratio (V̸) of concrete modified with paper ash. Poisson ratio can be defined as the ratio of lateral strain (εl) to longitudinal or axial strain(εa)

$$V = -\frac{\varepsilon l}{\varepsilon a} \qquad \text{eq 2}$$

It can also be obtained from the equation below.

$$V = -\{(\frac{E}{2G}) - 1\} \qquad \text{eq 3}$$

Where E = Modulus of elasticity

G = shear modulus of concrete = 21.045Gpa

Table 8: Poisson's ratio of modified concrete with low dosage of waste paper ash.

%	7	14	21	28
0	0.36	0.35	0.31	0.31
5	0.35	0.30	0.33	0.29
10	0.41	0.43	0.41	0.41
15	0.35	0.34	0.41	0.30

According to the mathematical model mentioned earlier, it is observed that as the compressive strength and modulus of elasticity of concrete increase, Poisson's ratio decreases. Both conventional and modified concrete exhibit Poisson's ratios falling between 0.31 and 0.41.

I. Mathematical Predictive Model for Flexural Strength

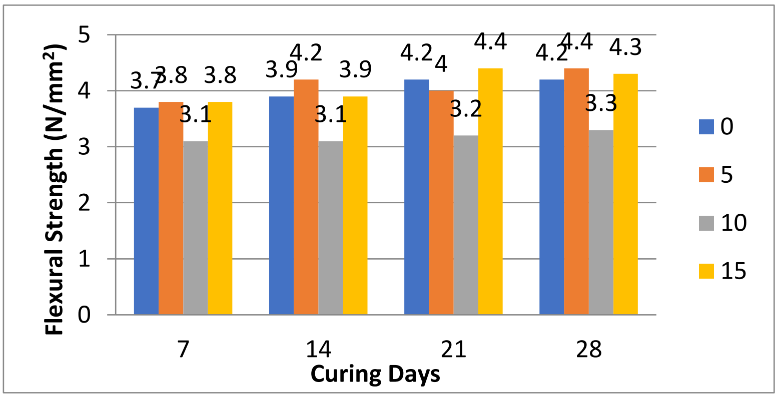
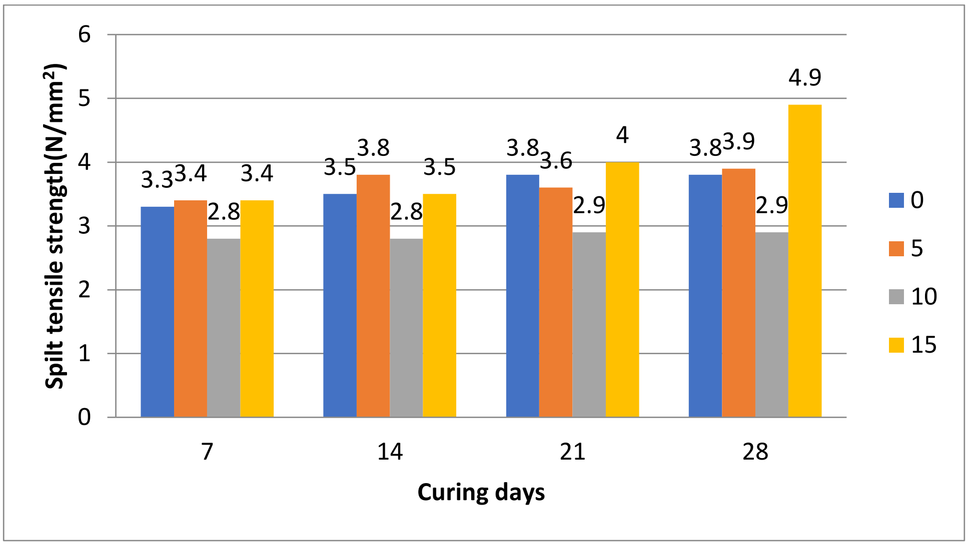


Figure 6: Flexural Strength(N/mm^2) Against Percentage Replacement of Cement Using WPA

The model was developed using relationship between compressive strength and flexural strength from I.S. 456-2000 that state''Fst = 0.7fck$^{0.5}$'' According to Figure 6 above, the predicted 28-day flexural strength of the control specimen (beam) was 3.89 MPa. This value was predicted to increase to 4.4 MPa with a 5% substitution, representing a slight increase of 0.2 MPa compared to the control. However, the strength dropped to 3.3 MPa at a 10% substitution before climbing back up to 4.3 MPa at a 15% substitution.

J. Mathematical Predictive Model for Spilt Tensile Strength



The model is derived from the equation $f_{sp} = 0.56\ fck^{1/2}$ that links compressive strength to split tensile strength. The pattern for split tensile strength was the same as for split flexural strength.

APPLICATION IN STRUCTURAL DESIGN OF REINFORCED CONCRETE BEAM

Consider a simply supported beam with an effective span of 5 meters subjected to a dead load of 20 kN/m and an imposed load of 5 kN/m. Determine the necessary and actual area of reinforcement for the beam.

Ultimate design load $w = 1.4G_K + 1.6Q_K$ (BS 8110; 1997)

$G_K = 20KN/m, Q_K = 5KN/m$

$w = (1.4 * 20) + (1.6 * 5)$

$= 36kKN/m$

$$M = \frac{wl^2}{8} = \frac{36 * 5^2}{8} = 112.5KNm$$

$b = 225mm, h = 450mm, d = 412mm, f_{cu} = 26.82N/mm^2\ (15\%\ substitute\ of\ OPC\ to\ WPA\ \ 28days\ compressive\ ), f_y = 380N/mm^2.$

$$K = \frac{M}{f_{cu}bd^2} = \frac{112.5 * 10^6}{26.82 * 225 * 412^2} = 0.11$$

$$z = d(0.5 + (0.25 - \frac{k}{0.9})$$

$$Z = 412\sqrt{}[0.5 + \left(0.25 - \frac{0.11}{0.9}\right)]$$

$Z = 354.32mm$

$$A_{Sreq} = \frac{M}{0.87f_y z}$$

$$A_{Sreq} = \frac{112.5 * 10^6}{0.87 * 380 * 354.32}$$

$= 960.40mm^2$

$A_{sprov} = (3Y20 + 2Y20)(1010mm^2)$

$If\ f_{cu} = 25.56N/mm^2$ for control specimen

$$K = \frac{112.5 * 10^6}{25.56 * 225 * 412^2}$$

$K = 0.115$

$Z=412\sqrt{}(0.5 + \left(0.25 - \frac{0.115}{0.9}\right)]$

$Z = 349.91mm$

$$A_{Sreq=}\frac{112.5 * 10^6}{0.87 * 380 * 349.91}$$

$= 972.51mm^2$

$A_{sprov} = (3Y20 + 2Y20)(1010mm^2)$

Cement

Volume of concrete = 0.225*0.45*5= 0.50625m^3 as control specimen at 28 days which developed compressive strength of 25.56N/mm2 with design mix ratio of 1:2:4 with water-cement ratio of 0.5.

Volume of cement = $\frac{1}{7} * 0.50625 = 0.0723m^3$

Weight of cement= $0.0723 * 1440 = 104.14Kg$ will be used to cast beam of 225*450*5000

Weight of WPA= $\frac{15}{100} * 104.14 = 15.62kg$ at 28 days

This means weight of cement that will be required to cast beam of 225*450*5000

$= 104.14 - 15.62 = 88.52Kg$ at 28 days

15.62kg of cement will be saved.

15.62kg of WPA equivalent to 104.14 kg of cement

1Kg of cement = $\frac{15.62}{104.14} = 0.15kgofWPA$

$1\ Bagofcement = 50Kg = 0.15 * 50 = 7.5KgofWPA$

7.5kg of WPA is required for one bag of cement, 42.5kg of cement not up to 1bag of cement saving 7.5kg of cement.

Reinforcement

Although the same area of reinforcement but there is difference in the area of steel required

Which is $972.51 - 960.40 = 12.11mm^2$; Design ratio of steel for 4% replacement of cement with WPA

Will give$\frac{960.40}{1005} = 096. < 1$,

Then for control with OPC

will give$\frac{972,51}{1005} = 0.97 < 1$

It can be deduced that reinforced steel in WPA concrete has better performance ratio than reinforced steel in conventional concrete since $0.96 < 0.97$.

IV. CONCLUSION

This study investigated the feasibility of partially replacing cement with paper waste. Specifically, it explored the use of paper ash as a substitute for cement at percentages of 0, 5, 10, and 15, examining parameters such as slump, compressive strength, and unit weight. The following conclusions were drawn from the findings: The utilization of paper waste in cement production did not result in any significant negative effects on the properties of cement.

1. The utilization of 15% proportions is a prevalent practice when incorporating waste paper ash as a substitute for cement.

2. Using paper waste in cement production serves as a means of environmental cleanup by removing paper trash from the environment. This practice is not only economically beneficial, leading to cost reduction, but also contributes to a reduction in the consumption and demand for raw materials such as cement and coarse aggregate.

3. It has been found that incorporating waste paper ash (WPA) as a substitute for cement not only decreases the demand for cement but also enhances the performance of reinforced steel within concrete structures.

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