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Structural Characteristics of Concrete Produced with Coal Ash and Jute Fibre for Sustainable Engineering

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ABSTRACT: This study investigates the structural characteristics of concrete produced with coal ash and jute fibre, aiming to enhance the material's sustainability and performance. The research begins with the collection of coal ash, a byproduct of coal combustion, which is often disposed of in landfills. By utilising coal ash as a full replacement for cement, the study aims to reduce the environmental impact associated with cement production and waste disposal. Moreover, jute fibres, a natural and renewable plant-based material, are introduced to improve the concrete's mechanical properties and mitigate cracking. The investigation involves a comprehensive experimental program, including the evaluation of fresh and hardened properties of concrete incorporated with varying proportions of jute fibre which are 0.0% and 1.0%. The fresh state properties comprise workability, slump, and setting time, while the hardened state properties include compressive strength and durability performance.

KEYWORDS: Concrete, Coal Ash, Jute Fibre, Sustainability, Structural Characteristics, Supplementary Cementitious Materials, Environmental Impact, Sustainable Engineering.

I. INTRODUCTION

Due to the rise in concrete consumption for infrastructure development, concrete is utilised most often in building construction (Mehta, 2001). Concrete will become more in demand in the future. Portland cement, aggregates, and water are the main ingredients in concrete. Carbon dioxide (CO₂) is released into the atmosphere during cement production. Traditional concrete, which contributes to environmental contamination, thus endangers human life and safety. As a result, numerous researchers investigated the manufacture of concrete using cement substitutes made from environmentally acceptable ingredients (Malhotra, 1999).

In comparison to regular concrete, geopolymer concrete is more durable (Malhotra, 2002). Geopolymer possesses great sulphate resistance, low creep, low shrinkage, and high compressive strength, according to (Wallah and Rangan 2006). Additionally, it was discovered that geopolymer exhibits superior fire resistance and great mechanical performance (David., 2011). Geopolymer is also notable for its fast setting and high early strength features, low production costs, and low energy consumption that results in little CO₂ emissions. (Duxson et al 2007).

Similar to other brittle materials, end geopolymer concrete made of coal ash requires natural and synthetic reinforcement fibre to enhance its elastic qualities and boost its mechanical performance. Fiber can improve ductility and tensile strength in addition to the toughness, optimizing the mechanical performance of geopolymer concrete. Natural fibres may be desirable as a source of reinforcement from an environmentally beneficial perspective. Investigating natural fibres including bamboo, cotton, coir, jute, and pineapple leaf fibre is necessary.

Jute is a great natural fiber for making environmentally friendly geopolymer concrete. Due to its low cost and availability, jute fiber, which is derived from annual plants and is widely available, may be considered a suitable material for concrete composites. They have pentagonal or hexagonal cross forms and are a great alternative for outdoor use because they are soundproof, extremely violent protection, and durable (Chen and Yu., 2005). The jute fiber-reinforced composites meet the requirements for commercial materials in terms of structural properties while maintaining a relatively low cost (Mohanty et al., 2001). Therefore, the physical characteristics of jute fiber in a coal ash based geopolymer concrete as well as the mechanical and durability aspects of geopolymer concrete made of coal ash and reinforced with jute fiber are the main emphasis of this research.

II. LITERATURE REVIEW

Numerous authors have studied jute fiber concrete, and some of them have reviewed summaries in the research they have conducted. Some of the most pertinent papers are studied, and different inferences are made based on the test results.

Harpreet et al (2018) Jute fiber is increasingly being used as reinforcement in the production of composite materials as a result of the increasing environmental stress brought on by rising fuel prices, the depletion of fossil fuels, and the effects of climate change, which compel researchers to focus on developing green composites. Jute fiber reinforced composites also take the place of outdated materials like steel and wood. The purpose of the research was to shed light on the issues and difficulties encountered in the creation of jute fiber reinforced composites. It has been determined how various types of jute fiber reinforced composites are constructed, and its mechanical characteristics have been published. Scanning electron microscopy has been used to analyse the failure mechanisms of jute fiber composites.

Jumana and Hariharan (2019) Studied concrete with jute as an admixture and rubber as an aggregate, this researchers discovered that adding tyre chips increased the concrete's compressive and flexural strengths by 23% and 6.3%, respectively.

Raval and Umang (2018) The distinguishing features of concrete following the addition of jute fibers were studied, and it was discovered that the addition of jute fibers improved the split tensile and compressive strengths to 10% and 33%, respectively, and that a larger fiber aspect ratio causes a reduction in the strength characteristics.

Dayananda et al. (2018) have investigated the Compression Test Properties of Reinforced Cement Concrete using Jute Fiber Composites and concluded that the addition of jute fibers raised the compressive strength results of regular concrete specimen from 8.8 N/mm² to a maximum of 44.44 N/mm²

Goel et al. (2017) Jute fiber reinforced concrete was studied, and it was determined that after breaking, the ductility of the concrete increased because stress was transferred across the cracks, and the fibers caused the cracks to spread quickly, extending the strain life past the limit.

Rahul et al.(2016). has conducted research on the applications and advancement of jute fiber in reinforced cement concrete grade M40 and discovered that adding 1% weight of raw jute to concrete increases the concrete cube's compressive strength by 17.5% and by 26.5% when adding modified jute.

Bostanci (2020). In his study, coal ash waste was used as a Portland cement replacement by 10% and 20% for the production concrete mix concrete mix with 28-day design strength of 45 N/mm². Developed mixes were tested against various engineering properties including workability, bulk density, compressive strength, sound permeability, thermal conductivity, water permeability and porosity. Results showed that coal ash incorporated mixes had slightly lower slump values with slightly lower fresh density. Hardened properties including bulk density and compressive cube strength were reduced slightly for CA mixes. Other hardened properties showed that CA mixes had more compact

structures compared to conventional mix. Therefore, CA mixes showed enhanced sound permeability, thermal conductivity, water permeability and porosity.

III. MATERIALS AND METHODS

The following materials will be used in carrying out the experiments

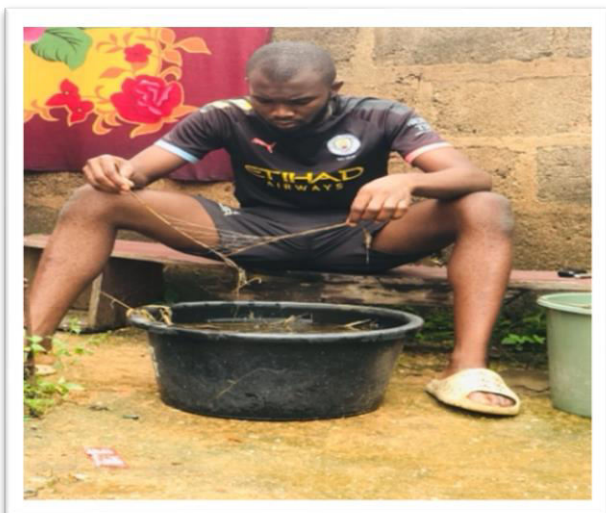
COAL ASH: The Coal ash was used in the Type 2 Concrete mix. Coal ash was used to replace ordinary Portland cement (OPC) completely in the type mentioned earlier. It was obtained in a 50kg bags from a coal combustion site in Enugu State.

FINE AGGREGATE: The sand used in this research is natural river sand, with fines less than 0.125mm. The sand was dried at room temperature for 24 hours to control the water content. Sand was gotten from around Anambra state

COARSE AGGREGATE: The nominal maximum size did not exceed 20mm size of coarse aggregate. Crushed aggregate was gotten from around Anambra state , with a nominal size of 19mm following BS 822 (1992) was used.

WATER: Portable water was used for concreting and curing of samples. Water is needed for the hydration of the concrete and to provide workability during mixing and placing.

JUTE FIBRE: After Jute fiber was obtained from the stalks of the jute plant. By harvesting, the stalks of jute plants are brought together and immersed in water for about 20 to 25 days. Jute Fibre was then separated from the stem and washed in clear running water. Jute Fibre was then spread out and hung up to dry for at most 2-3 days. The dried jute Fibre was then collected in its long strands and then cut into little pieces which are suitable for the concrete mix. The jute plant was gotten from a vegetable farm in Abuja before it undergoes the above process.



(a)



(b)

Figure 1, (a): extraction of jute fibre (b) drying process of jute fibre from jute plant

ALKALI ACTIVATOR: The starter material was activated with an alkali solution of sodium hydroxide (NaOH) and a silica-rich (Sodium silicate Na_2SiO_3) source. Chemical process known as alkaline activation where in a fine alumina silicate. Coal ash was combined with an alkaline activator to create a paste that can set and taking a reasonable amount

of time to harden. The part of Alkali activator solution is used to dissolve the silica and aluminium reactive components found in Coal ash and to provide a highly alkaline liquid medium for condensation. The activator for alkaline has a significant impact on geopolymer concrete. Alkaline activator is important in the hydration of binders. Mortars and alkaline activated concretes properties can provide results with stronger mechanical resistance than those derived from an OPC-made concrete. We got the alkali solution from a Chemical vendor at Onitsha. Anambra state .

CALCIUM OXIDE (CaO): It was show in Table 2.1 that coal ash has a little percentage of CaO in it and The Portland cement has a large amount of CaO which is also known as Lime. The presence of lime in a sufficient quantity is required to form silicates and aluminates of calcium. Deficiency in lime reduces the strength of the property to the coal ash. Lime was gotten from a chemical vendor at Pleatu State.

CALCIUM CHLORIDE (CaCl₂): Calcium chloride is a preferred additive for accelerating coal ash hydration and reducing set time for concrete applications,. It can enable concrete to be produced faster. Calcium chloride was gotten from a chemical vendor at Plateau state.



Figure 2: compressive strength cube samples after demoulding

IV. RESULTS AND DISCUSSION

The presentation of results, the analysis and interpretation of data obtained from the practical done. The said data were presented in tabular form in accordance to specific value, readings and calculation done.

QUANTITY OF MATERIAL USED IN MIX 1-2

| Mix No. | % of jute fiber | No of cubes | Total vol of concrete | Qty of coal ash (Kg) | Qty of fine Agg (Kg) | Qty of Coarse Agg (Kg) | Qty of jute fiber (Kg) |
|---------|-----------------|-------------|-----------------------|----------------------|----------------------|------------------------|------------------------|
| 1 | 0% | 6 | 0.021m ³ | 7.20 | 14.40 | 28.80 | 0.000 |
| 2 | 1% | 6 | 0.021m ³ | 7.20 | 14.40 | 28.80 | 0.096 |

Table 1: quantity of material used

SLUMP TEST

This test was carried out in order to determine the workability of jute fiber utilised at varied volume fractions of 0% and 1%. The results obtained were presented in Table 4.2 Mix Ratio: 1:2:4. Concrete Grade: M15. Water Cement Ratio: 0.5 The slump test result showed that as the fibre is added, the workability reduces.

| Mix No | Jute Fiber | Height of cone | Height of Slump Concrete | Slump value | Type of Slump |
|--------|------------|----------------|--------------------------|-------------|---------------|
| 1 | 0% | 300mm | 210mm | 90mm | True Slump |
| 2 | 1% | 300mm | 260mm | 40mm | True Slump |

Table 2: Table Of Slump Test Value



Figure 3 (a)&(b): Slump test of coal ash with different percentage of jute fibre

COMPRESSIVE STRENGTH TEST

Table 3 presented the compressive strength of the crushed cubes of coal ash and jute fibre at different percentages .

| Mix No. | Percentage of jute Fibre | 7 days | | 14 days | | 28 days | |
|---------|--------------------------|-------------------|---|-------------------|---|-------------------|-----|
| | | N/mm ² | | N/mm ² | | N/mm ² | |
| 1 | 0% | - | - | - | - | 4.0 | 7.8 |
| 2 | 1% | - | - | - | - | 5.7 | 8.3 |

Table 3: compressive strength test results for coal ash and jute fibre

Table 4 presented the compressive strength of the crushed cube of Portland Cement

| Mix No | 7 days N/mm ² | | 14 days N/mm ² | | 28 days N/mm ² | |
|--------|-----------------------------|------|------------------------------|------|------------------------------|------|
| | 1 | 12.8 | 14.3 | 15.7 | 16.4 | 20.0 |

Table 4: Compressive Strength Test Results For Portland Cement

From table 3 shows the compressive strength test of both coal ash and jute fibre at different percentage for 7, 14, and 28 days. Due to the Observation of the cube samples after demoulding and left for 7 days for curing under standard room temperature. It was observed that the cube samples did not dry properly and water was still retained at the bottom part of the cube samples and could not be tested cause it has not achieved a proper hardened state for the compressive strength test. So for the day 7, the test was not conducted.

Also from observation at day 14 of dry curing under standard room temperature, the cube samples still had little water at the bottom of the cube. But gained strength physical than that of day 7 which was still not enough to conduct the compressive strength test. So for day 14 test was not conducted. The cube samples was left till day 28, which after proper observation the cube was tested for it compressive strength. For the cube samples with 0%. Of jute fibre had an average compressive strength of 4.0 – 7.8 N/mm². The cube samples with 1% of jute fibre had an average compressive strength of 5.7 – 8.3 N/mm².

While table 4 shows the compressive strength test of Ordinary Portland Cement concrete at 7, 14 and 28 days. The result shows the average compressive strength for 7 days ranged from 12.8 – 14.3 N/mm². , The 14 days ranged from 15.7 – 16.4 N/mm² and the 28 days ranged from 20.0 – 21.7 N/mm². (Troxel et al. 2018). Comparing the compressive strength test results of coal ash and jute fibre at different percentage and that of OPC for 28 days shows coal ash with 1% of jute fibre had more strength than coal ash with 0% jute fibre. While when compared with OPC it has shown that OPC had more strength to resist load than that of coal ash reinforced with or without jute fibre.

V. CONCLUSION

This laboratory investigation defined the production of geopolymer concrete using coal ash to replace cement and jute fibre as reinforcement. The mixing was found not to be different in characteristics with usually consistent behaviour. The slump test showed that the workability and consistency of geopolymer concrete of coal ash replacement is still in line with the BS specifications. The research is in line with the practices or policies that do not adversely impact the environment, this would have a dual positive impact on the environment by reducing the need for raw materials. The optimal amount of coal ash to replace OPC was 100%

The findings show that the use of coal ash to replacement OPC fully was not successful. It was discovered that adding jute fibre to the mixture increased the compressive strength of the geopolymer concrete slightly. But also discovered OPC concrete had a greater compressive strength than the geopolymer concrete. It was also observed that the coal ash concrete has a slow setting time unlike OPC concrete. It was also discovered that Unlike OPC concrete, Coal ash concrete does not need wet curing, rather it should be either keep at a standard room temperature to dry or should be oven dried

Therefore, the study encourages more researcher to look into ways and means to enhance the strength of coal ash concrete and also ways to increase the setting time of coal ash concrete, so it could set faster. Further study on the production of geopolymer concrete using coal ash as a full replacement for Ordinary Portland Cement is greatly advised

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