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AN OVERVIEW: INVESTIGATING THE EFFECT OF COCONUT FIBRE ASH ON THE FLEXURAL STRENGTH OF RE-VIBRATED CONCRETE BEAM

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ABSTRACT
Previous studies have reported findings about the possibilities of using coconut fibre ash (CFA) to partially replace cement in the production of concrete. Based on the outcome of previous findings, there is a need for further research to determine the degree of the suitability of using the CFA in re-vibrated concrete beam. This becomes inevitable because some studies reported positive contribution to the compressive strength of concrete with less emphasis on the flexural strength of re-vibrated concrete beam. This study highlights the chemical and physical properties of CFA as reported by previous studies and compared these properties to those of cement. The properties of fresh and hardened concrete that were produced using CFA as partial replacement for cement, as reported in previous works are presented and discussed in this study. Based on the outcome of this study, it has been found that, CFA is a good pozzolona due to its high percentage of silicon oxide, it is readily available and there is a need for large volume consumption of the agricultural waste material. Re-vibrating concrete reduces voids, increases density and strength of the concrete which tends to improves both the compressive and flexural strength of re-vibrated concrete beam.

Keywords: *Concrete properties; Coconut fibre ash; Pozzolana; Re-vibrated concrete; Flexural strength*

1 INTRODUCTION

The most used engineering material for construction in the world today is concrete. Conventional concrete manufacture substantially makes a significant to CO_2 emissions because of the high energy needed to generate Portland cement, the main binder of concrete (Kahan *et al*. 2023; Althoey *et al*. 2023). Recent searches have stated that roughly 0.9 tonnes of CO_2 are released while manufacturing 1 ton of Portland cement, which accounts for approximately 5% of the human-induced CO_2 emissions globally (Althoey *et al*. 2023; Nassar *et al*. 2022). Therefore, in recent years, a vast majority of researchers have searched for sustainable resources for environmentally friendly cement and concrete, to decrease CO_2 emissions. Due to a substantial surge in the demand for sustainable concrete, which is one of the most extensively utilized construction materials globally (Althoey *et al*. 2023).

The over-reliance on the usage of concrete produced from cement (as a binder) for buildings have kept their cost high and this has prevented low-income earners in developing nations of the world from building houses for their local dwellers that make up the greater percentage of their population and most often are agriculturally dependent (Aguwa *et al*.,2016). As a result of the high cost of acquiring the required materials to construct functional and stable houses, a greater proportion of the country's population cannot afford the cost (Aguwa,2009). An easy way out of this, points at suitable means of replacing a proportion of cement with cheap and easily obtainable pozzolanic materials. In (ASTM C618,2012) defined pozzolana as "siliceous or siliceous and aluminous material which in themselves have little or no cementitious properties but in finely divided form and the presence of moisture, react with calcium hydroxide which is liberated during the hydration of Portland cement at ordinary temperatures to form compounds possessing cementitious properties". The global increase in human population has triggered an increase in the demand for scarce and expensive engineering materials for building and engineering infrastructure construction.

Concrete according to (Anzar,2015), is that pourable composite mix of cement, fine aggregates, coarse aggregates and water in the right proportion that hardens into a super-strong material for building. When concrete is re-vibrated, it momentarily liquefies again. The primary chemical process that occurs in the first 120 minutes after the concrete is placed, is the formation of calcium hydroxide, which typically makes up 15 to 25 percent of ordinary Portland cement concrete. The other major product of hydration is calcium silicate hydrate, which usually constitutes about 50% of OPC concrete which gives the concrete its hardness and durability. Initial vibration of concrete may not eliminate defects such as honeycomb and voids causing a reduction in strength and performance. But re-vibration can eliminate such defects (honeycomb and voids) and thereby increasing bond, improving concrete quality, better impermeability, reduction in shrinkage and creep, increasing the compressive strength of the concrete, reduction in surface and other voids as well as cracks in fresh concrete and so on (Krishna et al.,2008). According to (Auta *et al.*, 2015) RHA is not recommended to be used as partial replacement for cement in concrete when re-vibration is not envisaged as it results in concrete having very low compressive strength at all ages of curing. An average duration of 90 minutes is recommended for re-vibration of concrete with 20 % RHA as cement replacement for optimal or higher compressive strength. An investigation was conducted on the usage of wood waste ash as a partial replacement for cement in the production of mortar and structural grade concrete, assessment of the fresh concrete properties of self-compacting concrete containing SDA, and it was evident that ash from timber waste was a material capable of replacing cement (Elinwa *et al.*,2008).

Much work has not been reported on the behavior of re-vibrated concrete beam produced from coconut fibre ash (CFA) as a partial replacement for cement. As such, this study aims to examine the effect of CFA on flexural strength of re-vibrated concrete beam made from 0%, 5, 10, 15, and 20% replacements of OPC.

2 Physical Properties of Coconut Fibres

Coconut fibre, also known as coir, is derived from the fibrous husk of the coconut plant and is used in the production of coir. Coconut fibres are mostly brown in color with varying lengths and diameters. More-over, other properties such as tensile strength and modulus of elasticity vary depending on the source and usage. A different researcher reported different physical properties of coconut fibre. The details of the physical properties of fibres as per past researchers (Naveen *et al.*, 2013: Tensile strength is 175Mpa, water absorption 130 to 180 %, elongation 30 %; Amadi *et al.*, 2013: Length 25mm, diameter 0.25mm, aspect ratio 100, tensile strength 405Mpa; Bai *et al.*, 2019: Length 18mm, diameter 0.1 to 0.5mm, density 0.67 to 10g/cm^3; Ramakrishna *et al.*, 2005: Length 8 to 10mm, diameter 0.5 to 1.0mm, tensile strength 15 to 327Mpa; Ahmad *et al.*, 2021: Length 20 to 30mm, diameter 0.32mm, tensile strength 176MPa, modulus 22.4GPa.

3 Fresh Properties

Concrete workability is a term that relates to how easily mixed concrete can be placed, compacted, and finished while retaining it homogeneity to the greatest extent possible. Unworkable concrete is one that cannot be easily worked. In unworkable, the cement paste is not sufficiently lubricated and it does not adhere to the aggregates correctly, resulting in significant aggregate segregation. Maintaining the homogeneity of an unworkable concrete mix is very difficult, and compaction of concrete requires a significant amount of work, which has a negative impact on the mechanical and durability performance of concrete.

According to one study, the value of slump flow decreased when the dose of coconut fibres was raised. The increased surface area of coconut fibres requires more water to cover, resulting in less free water for flowability. Moreover, CFA increased internal friction among concrete elements, necessitating more cement paste (Ahmad *et al.*, 2020). Adding 0.25 percent coir fibre (by weight of aggregate) reduced slump to 50mm. The slumps of the following variants indicate decreasing values with increasing coir fibre content. This propensity is due to the coir fibres surface shape and physical qualities (Rumbayan *et al.*,2019). According to one study, coir fibres have hydrophilic surfaces and hence repel water (Ahmad *et al.*,2021). In similar manner, several studies have shown that the slump value decreases when coconut fibre is included (Ali *et al.*, 2012; Pierad *et al.*, 2013; Zhang *et al.*, 2019).

According to one study, fresh density rose as the proportion of coconut fibre increased upto 2.0 percent, after which it decreased when compared to reference concrete. Coconut fibre at a dose of 2.0 percent exhibits the highest fresh density when compared to reference concrete (0 percent addition of coconut fibres). However, the fresh density was lowered with the addition of coconut fibres, with a minimum fresh density of 3.0 percent when compared to other coconut fibres reinforced concrete. The increase in fresh density of concrete reinforced with coconut fibre is related to crack prevention since CFA reinforced concrete has fewer plastic shrinkage voids and produces denser concrete (Althoey,2021). However, with the 4 percent addition of CFA, compaction becomes problematic, resulting in porous concrete and lower fresh density. A study claims that adding 1.5 percent CFA by volume to concrete increases density by 15% as compared to the reference concrete (Tadepalli et al., 2013). In contrast, when the fibre content of a specimens increased, the density of the specimens dropped (Ahmad et al., 2020). Due to the fact that fibres are light, their addition to concrete causes cavities in the matrix, which reduces the density of the concrete. As a consequence of the inclusion of low-density coconut fibres, a phenomenon is known as the "filled void effect" occurs, which decreases the density of the concrete when compared to palin concrete (Syed et al., 2020).

Density is an important factor that influences the flowability of concrete. A lack of workability leads to void in occupied space and reduced density (Ramli *et al.*,2023).

4 TREATMENT OF COCONUT FIBRES

To investigate the durability of coconut fibre, several treatments were carried out on the material. For the first minute, each fibre was soaked in an adherent solution (deionized water or natural latex) to ensure that it adhered to the other fibres. During this process, the adherent solution surrounds the coconut fibre, forming bonding layers between the two materials. A coating agent was then applied, which consisted of pozzolanic materials (silica fume or metakaolin). Pozzolans are attracted to the coconut fibre by the adhering solution in which they are dissolved. The production of "chicken fingers" is comparable to the process used in the development of this novel medicine (da Silva *et al.*, 2022).

Using a latex polymer film and a pozzolan layer, the coconut fibre treatment was created to increase the flexural strength and durability of cement-based composites. The performance of the sample treated with silica fume and natural latex was 42.2 percent better than the performance of the sample without any treatment. When fibre samples were subjected to degradation tests, the mass conservation rate increased as a consequence of this treatment (silica fume and natural latex). This treatment resulted in an enhancement in the retention of fibre against the degradation process, according to the microstructural examination of the treated fibres isolated from CF. This treatment (silica fume and natural latex) has the potential to be a viable alternative to the use of CF in the creation of novel cementitious composite materials that have appropriate performance and long-term durability. The compressive and flexural strengths of the structures increased by up to 13 percent and 9 percent, respectively, according to the testing data. However, in terms of durability, the chloride penetration, intrinsic permeability, and carbonation depth increased with CF. The authors propose that the CF could be treated before being used in concrete to ensure that is protected against deterioration (Ramli *et al.,2022).* Coconut fibres were immersed in NaOH solutions with concentration ranging from 2 to 10% for four weeks. The authors discovered that the tensile strength reduced as the concentration of NaOH increased, which they attributed to the fibres becoming more fragile (Wang *et al.*, 2021).

5 MECHANICAL PROPERTIES

5.1 Compressive Strength: is a material's or structure's capacity to bear loads without cracking or deflection. Compression shrinks a material's size. Concrete compressive strength gives an indication of the concrete properties. This single test determines whether or not concrete was correctly performed. In commercial or industrial construction, concrete's compressive strength ranges from 15N/mm2 to 30N/mm2. Compressive strength is tested on a cube or a cylinder. The American Society of Testing Materials established ASTM C39/C39 for compressive strength testing of cylindrical concrete specimen.

Research also found that fibres increased concrete's compressive strength up to a certain point before decreasing owing to a lack of workability (Ahmad et al., 2020). Even at a larger dosage, the compressive strength of concrete is lower to that of reference concrete. The fibre reinforcement's confinement on the specimen has a favorable impact on compressive strength. Compressive results in lateral expansion, which is limited by the coconut fibres (CF), resulting in increased compressive strength. Because of their strength, the fibres can sustain strain and shear (Ahmad et al., 2020). Compaction becomes problematic at larger dose (more than 2.0%) owing to a lack of workability, resulting in decreased strength. A study reported that in compression to reference concrete, 1.5 percent of the fibres enhanced compressive strength by over 15% (Tadapalli et al.,2013). At 1.0% by volume, fibres significantly improve the mechanical performance of concrete at both the initial and later ages. The greatest 28-day strength increase was found to be 29.15% (Usman et al.,2020). As a result, coconut fibre has an ideal limit. The experiments indicate that the best dosage of coconut fibre for strength is 2.0% by weight of cement (Ahmad *et al.*,2021).

A study indicates that the optimal quantity of coir fibre in concrete is 0.25%, which results in a 19% increase in 28-day compressive strength (Rumbayan *et al.*, 2019). However, the optimum dose of fibres varies depending on the type of fibre, the physical aspect such as length and diameter, as well as the concrete mix design and the water-to-binder ratio. A study reported that in CF of 50 mm to 75 mm long, the compressive strength decreases with the increase in fibre content. The decrease in compressive strength could be attributed to the decreased workability of fresh concrete caused by the increased content and length of fibres, as well as the lack of proper compaction during specimen casting, resulting in the formation of air voids. It might be possible due to the dilution of the cement matrix/hardened cement paste caused by the addition of fibres (Ahmad *et al.*,2020).

5.2 Flexural Strength: Flexural strength is the capability of an unreinforced concrete beam or reinforced concrete beam to withstand bending failure. According to ASTM standards, it is by loading 150mm by 150mm concrete beam with a span length that is at least three times the depth (ASTM,2010).

Research found that, when the percentage of coconut fibre is raised by the weight of cement up to 2.0%, the flexure strength improves, but subsequently drops when the percentage of CF is further increased as compared to a reference or standard concrete (Kikuchi et al.,2020).

The inclusion of CF at a rate of 2.0% resulted in the greatest possible flexure strength. After the addition of CF at a rate beyond 2.0%, the flexure strength gradually reduced. The flexural strength of all coconut fibre reinforced concrete is much higher than that of ordinary concrete. Coconut fibre increase flexural capacity by inhibiting the development of fracture. Because of the interfacial between the concrete components and the coconut fibres, the load is quickly transmitted to the coconut fibres. The breaking of cracks is prevented by coconut fibres, which allow the crack to flow around the fibres and transfer the stress. The coconut fibres and concrete matrix resist the load as a whole, resulting in increased flexural strength for the structure (Usman *et al.*,2020). The compaction process becomes more complicated as the quantity of fibre in the mixture increases. Using higher dosage, such as 3.0%, the workability of the concrete worsened, causing porous concrete and drop in flexural strength. According to other findings, the best quantity of CF IS 0.25%, which results in 19 % increase in 28-day flexural capacity (Ali *et al.*,2019). Table 1 shows a summary of the flexural strength of concrete with different doses of CF.

Table 1. Summary of mechanical performance of concrete with coconut fibres.

Author	Percentage of Replacement	Compressive Strength (MPa)	Flexural Strength (MPa)
Abbas *et al.*, (2021)	0 0.1 0.2 0.3 0.4 0.5 0.6	36 38 38 36.5 35 33.5 30	4.8 5.2 5.4 4.98 4.85 4.75 4.50
Srinivas *et al.*, (2021)	0 0.5 1 1.5	8.0 8.66 9.93 4.75	6.33 3.23 3.82 2.80
Kumar *et al.*, (2020)	0 CF: 5% CF ASH: 15%	22.3 19.53 34.87	6.73 5.27 5.33
Khan *et al.*, (2020)	Silica Fume: CF 0:2 5:2 10:2 15:2 20:2	27.2 27.5 28.8 32.4 26.6	6.2 6.6 7.8 8.3 4.7
Raj *et al.*, (2020)	0 0.3 0.4 0.5	9.5 11.5 8.0 7.5	1.4 1.7 1.2 1.1
Wongsa *et al.*, (2020)	0 0.5 0.75 1	31 33 28 25	3.2 5.3 6.2 6.7
Krishna *et al.*, (2018)	0 0.5 1 1.5 2	37.5 35 47.5 51 41.75	-

6 DURABILITY

6.1 Water Absorption

The water absorption test analyses the rate of water absorption of the outer and inner concrete surface. The test includes measuring the increase in mass of concrete samples caused by water absorption as a function of the time when the specimen is exposed to water. Higher water absorption results in less durability since water contains various hazardous compounds that seeps into the concrete, causing concrete breakdown and resulting in reduced durability.

Research revealed that with the addition of CF, the amount of water absorbed increased (Abdullah *et al.*, 2011). The effects of fibre volume fraction on heat conductivity and water absorption were not significant (Wongsa *et al.*, 2020). A study concluded that the water absorption decreases as the percentage of coconut increase up to 2.0% addition of CF, and decrease occurs gradually, with maximum water absorption observed at 0 % substitution and minimum water absorption observed at 2.0% addition of CF (Ahmad *et al.*,2021). It has also been reported that the inclusion of CF would result in an increase in the tensile strain characteristics of concrete, which would limit the creation and development of early fractures in the concrete (Huang *et al.*,2011). In other words, increasing concrete density reduces water absorption. Due to lack of workability, greater dosage (above 2.0%) resulted in less dense concrete. Because of the increased porosity of the coconut coir fracture mortar compared to the control mortar, according to one research, more water absorption was noticed in CF reinforced concrete than the control mortar. The porous structure of the cement blocks, as well as the presence of an interfacial zone surrounding the particles, are the most important elements influencing water absorption. The findings reveal that as compared to the control mortar; the coconut coir mortar noticed water absorption considerably in the greater amount (Sathiparan *et al.*,2017).

6.2. Permeability

The water absorption by immersion provides an estimate of the total pore volume of the concrete, but it provides no information on the permeability of the concrete, which is more essential in terms of long-term performance.

It is discovered that the permeability of concrete increased with the addition of CF. The continuous pore structure of the specimen has a significant influence on the permeability of the specimen (Hearn et al.,1994). Generally speaking, the wider the width of continuous pores, the more permeable the concrete would be considered to be. It is possible to produce continuous holes under a variety of situations, some of which include the capillary network formed by hydration, the interfacial transition zone between paste and aggregate, the production of micro-cracks, and others (Hearn *et al.*,2021). Not only the interfacial zones between the aggregate and the paste but there will also be a gap between the fibre and the matrix (Savastano and Agopyan, 1999). However, the authors hypothesized that there is another mechanism at work that is also responsible for the disparity. This gap may be linked to the strong water absorption characteristics of the coconut fibre, which is responsible for its existence. During the mixing process, a water film is formed around the fibre's immediate surroundings. The absorption capabilities of the film, as well as the osmosis pressure, will keep the film in place and cause the fibre to inflate. As the hydration process advances, the formation of the permanent shell structure starts to take place. As water is consumed by cement hydration and evaporation, the water film gradually vanishes, finally creating a gap between the fibre/matrix interfacial zone of the composite. When the fibre shrinks back to its former shape after inflating as a result of the drying process, the gap widens even further, creating a larger opening. According to the findings of a study, nitrogen gas travels through the natural fibre during the permeability test because the natural fibre has a porous cellular structure, increasing the likelihood of pore network connection during the test (Persson, 2000).

7 CONCLUSIONS

This paper presents a summary of research progress on coconut fibres. Coconut fibres are an inexpensive, recyclable, low-density, and environmentally acceptable building material. These fibres have excellent tensile qualities, and they may be utilized instead of traditional fibres such as glass and carbon steel fibres as partial replacement of cement in concreting. Based on a detailed review, the following conclusions have been made:

- The flowability of concrete decreased with addition of coconut fibre due to the larger surface of the fibre, which enhanced the internal friction among concrete ingredients, leading to less workability. Furthermore, an increase in fresh density is observed up to 2% addition of coconut fibres.
- Increased durability properties were also observed with addition of coconut fibres. However, less information is available in this regard.
- Mechanical characteristics such as compressive, split tensile, and flexural strength were improved up to a certain dose of coconut fibre, which depends on the physical properties

of fibres such as length, diameter, and aspect ratio. Furthermore, it can also be observed that coconut fibres improved flexure capacity (47%) more efficiently than compressive capacity (12%).

- The optimum dose of coconut fibres is the most important parameter for better performance of concrete, as a higher dosage results in more voids in hardened concrete due to lack of workability, leading to lower mechanical and durability performance of concrete.
- Re-vibration improves both compressive and flexural strength of fibres reinforced concrete beam.

It can be concluded that coconut fibres enhanced flexure capacity more efficiently than compressive capacity. Therefore, further research was recommended to add some pozzolanic materials such as silica fume and fly ash to improved compressive capacity of fibre reinforced concrete for high strength concrete. It is necessary to re-vibrate concrete when its still in it plastic form. It is also necessary to investigate a novel strategy that makes use of the water retention capacity of coconut fibres in order to generate high-performance cement composites using internal curing technology.

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