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Impact Resistance of Coconut Fibre-Reinforced Concrete

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Abstract
Concrete is often subjected to impact loads which reduces its service life. Natural fibres like coconut fibre have certain mechanical and physical properties that can be used to reinforce concrete against such loads. This study used the Charpy impact test to determine the impact resistance of different mix ratios of coconut shell fibre-reinforced concrete. The result revealed that a 3% inclusion of coconut fibre significantly enhanced the material's ability to withstand impact loads. The optimal proportion for maximizing impact resistance was identified as 3%. Concrete samples with a 1:1:2 mix ratio exhibited increased energy absorption capacity, emphasizing the impact of mix proportions on the material resistance to impact.

Keywords: Concrete, Coconut shell fibre, Charpy impact test, Impact resistance, Concrete mix.

1.0 INTRODUCTION

As a result of advancements in science and technology in the construction industry, the use of concrete as a structural material has grown astronomically (Odeyemi et al., 2022). Concrete structures are often subjected to impact loads which reduce their service life. Natural fibres like coconut fibre can be used to improve the properties of concrete against impact loads. Most often, these coconut strands are discarded as farm waste thereby constituting environmental nuisance (Odeyemi et al., 2017). Coconut fibre comes from the coconut's outer shell (Nayar, 2017). There are two types of coconut fibres, the brown fibre from mature coconuts and the white fibre from immature coconuts (Guambo et al., 2020). As a filler and reinforcement for composites, natural fibres like jute, sisal, pineapple, abaca, and coir have been studied (Marvila et al., 2021). Because of its accessibility, coconut fibre is getting increasingly more consideration nowadays. The Coconut fibre is made from coconut husk, which can be found in large quantities as a byproduct of coconut production. Natural coir is made of lingo-cellulose. This seed-hair fibre is produced from the coconut's outer husk or shell. It can be dyed and resists abrasion. There are 250,000 tons of coconut fibre produced worldwide (Rohit & Dixit, 2016). The use of natural fibres as a form of concrete enhancement is of particular interest, and the coir fibre industry is especially important in less developed regions where conventional construction materials are either unavailable or too expensive. Roof tiles, corrugated sheets, pipes, silos, and tanks have all been made from coconut and sisal-fibre-reinforced concrete (Jones et al., 2020). Concrete flexural strength, toughness, and impact resistance are significantly enhanced by coir fibres (Hwang et al., 2016). Portland cement-based concrete possesses several characteristics which include high compression but weak tension and tends to be brittle. To overcome the this weakness, , conventional steel bars and, to a lesser extent, the inclusion of a sufficient volume of specific fibres can both be utilized (Khan & Ali, 2018). Additionally, the use of filaments alters the fibre-network composite's behaviour after it has broken, thereby improving its strength. Coconut fibres are rarely used in the construction industry and are frequently discarded as waste.

Coconut fibres are agricultural waste products produced during the production of coconut oil. They are derived from the husk of the coconut and belong to the family of palm fibres (Reddy &

Yang, 2005). They are particularly prevalent in tropical regions like Asia, Africa, and southern America (Ramakrishna et al., 2010). In Nigeria, it has been demonstrated that cement and mortar can be made more durable by working with coconut fibre. The use of alternative, non-conventional local construction materials, such as the possibility of using some agricultural wastes and residues as a partial or complete replacement for conventional construction materials, has been one of the most prominent suggestions. Agricultural wastes can be utilized in the construction industry as additional or substitute materials where they are in large quantities (Olanipekun et al., 2006). An enormous amount of coconut fibre is produced in Nigeria and most of them are discarded by open burning. This method of waste disposal significantly contributes to air pollution and frequently occurs without any control. Therefore, to comply with environmental regulations, these leftovers must be disposed of in a more environmentally friendly manner. The conversion of coconut fibre into useful building materials is an effective method for disposing of these wastes (Bär et al., 1996).

Zhang et al. (2005) and Abdullah et al. (2011) reported that the incorporation of fibres into concrete reduces the size of craters and damage caused by impacts, as different researchers demonstrate that high-strength concrete is more resistant to impacts than regular concrete. However, their work did not report on the impact strength of the concrete. The composite reinforced with 9 % weight percent of coconut fibre had the highest compressive strength and modulus of strength. Aziz et al. (1981) looked into how different lengths and weight fractions of coconut fibres affected the properties of cement paste composites. It was concluded that the tensile strength and modulus of rupture of cement paste increased when the fibres of 38 mm fibre length and 4 % weight fraction were used. The strength of a composite could be decreased by adding more length or weight fraction. Baruah & Talukdar (2007) investigated the mechanical properties of plain concrete and fibre-reinforced concrete (FRC) with varying fibre volume fractions from 0.5 - 2%. The properties improved with the coconut fibre volume of 0.5%, 1%, 1.5%. Even the lowest fibre volume of 0.5 % improved the compressive strength, tensile strength, shear strength and modulus of rupture by 1.3 %, 4.9 %, 4.7 % and 4.0 % respectively. Lumingkewas et al. (2017) researched the effects of fibre lengths and fibre content on the splitting tensile strength of fibre-reinforced concrete (FRC). Fibre content of 1 %, to 4 % and fibre length of 5 to 40 mm were considered in the study. The findings showed that FRC had a splitting tensile strength that was 1.28 higher than that of plain concrete with 5 mm fibre and 3 % fibre content. However, incorporating coconut fibre decreases the density of the fibre-reinforced concrete. Li et al. (2007) looked into the amount and fibre percentage using a wetting chemical to treat the surface of the coir mesh mortar which can be strengthened by using non-woven coir mesh matting. They found that cementitious composites reinforced with three layers of coir mesh with a low fibre content of 1.8 % improved the maximum flexural strength by 40 % when subjected to a four-point bending test. Flexural toughness was 25 times higher and flexural ductility was about 20 times higher for the composites.

From the literature review above, a lot of the research was based on mechanical properties such as compressive strength, splitting tensile strength, and modulus of rupture, but there has been no significant research on impact resistance by fibre-reinforced concrete. This essentially motivated the cause of this research to determine the impact resistance of the fibre-reinforced concrete.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in this research were Dangote cement, a brand of Portland Limestone Cement (PLC) of Grade 42.5R with a specific gravity of 3.13; potable water; sharp sand passing through a 4.75 mm sieve with a fineness modulus of 2.8; granite chippings (of about 1 to 2 mm) meeting the standards specified in BS 12390 (2019) and coconut shells, shown in Figure 1, which were bought from Oja Oba, Ilorin, Kwara State, Nigeria.

Figure 1: Coconut fibres

2.2 Preparation of specimen

The coconut was soaked in water for five days before the husks were crushed to break up their fibres. The fibres were washed, dried, cleaned and brushed to remove impurities. The length of the fibres was measured and found to be between a range of 30 mm to 50 mm. For the impact test, four samples, each measuring 55 mm x 10 mm with a thickness of 10 mm and a V-notch, were prepared from each concrete mixture, resulting in a total of 72 specimens. The concrete specimens were cured for 7, 14 and 28 days. To prepare the samples, coconut fibres were evenly distributed in the pan mixer as the initial layer, concealed beneath a layer of sand, aggregates, and cement. Subsequently, an additional layer of fibres was uniformly applied, succeeded by another layer of sand, granite chippings, and cement. This sequence was reiterated until all the materials were introduced into the pan mixer. For each mix ratio, specimens were cast in four categories with fibre replacement levels of 0%, 1%, 2%, and 3%. This resulted in a total of 72 samples, with mix ratios of 1:2:4 and 1:1:2 representing the proportions of cement, sand, and granite in the concrete, maintaining a constant cement ratio of 0.56. The concrete mix designs for ratios 1:2:4 and 1:1:2 are presented in Tables 1 and 2, respectively. Figure 2 displays the samples both in their moulds and in the curing container.

(a) (b)

Figure 2: The samples (a) in a mould (b) in the curing container

Table 1: Mix proportion for 1:2:4 concrete samples (kg/m³)

Concrete mix	Cement	Sand	Granite dust	Fibre	Superplasticizer
1:2:4	450	900	1350	0	4.5
1:2:4	445.5	900	1350	4.5	4.5
1:2:4	441	900	1350	9	4.5
1:2:4	436.5	900	1350	13.5	4.5

Table 2: Mix proportion for 1:1:2 concrete samples (kg/m³)

Concrete mix	PLC	Sand	Granite dust	Fibre	Superplasticizer
1:1:2	450	450	900	0	4.5
1:1:2	445.5	450	900	4.5	4.5
1:1:2	441	450	900	9	4.5
1:1:2	436.5	450	900	13.5	4.5

2.3 Impact test procedure

In the Charpy impact test conducted at the Mechanical Laboratory of the University of Ilorin, Nigeria (Figure 3), a swinging weight attached to a swinging pendulum was used to strike the notched impact specimen. The specimen broke at its notched cross-section upon impact. The pendulum's upward swing was used to measure the amount of energy absorbed. This test was done in compliance with the procedure stated in ASTM D6110. The material's brittleness was directly related to its ability to absorb energy. The impact energy was calculated using Eq. 1.

$$E = 0.5\, mv^2 \qquad 1$$

Where impact energy (E) represents the quantity of energy absorbed by the material upon its fracture due to a sudden impact. The variables include 'm,' which denotes the mass of the moving object (such as a pendulum hammer), and 'V,' which signifies the velocity of the object at the moment of impact. Precautions taken during the experiment included ensuring that the swinging pendulum and weight were securely attached, properly aligning the notched specimen in the testing apparatus and safety measures were also taken to protect the operator from the swinging pendulum and potential fragments from the broken specimen.

Figure 3: Impact Testing Machine

3.0 RESULTS AND DISCUSSION

3.1 Materials properties

The properties of the constituent materials for the concrete are presented in Table 3.

Table 3: Materials Properties

Tests	OPC	Coarse aggregates	Fine aggregates
Fineness (%)	8.3	-	-
Fineness Modulus		7.16	3.76
Specific Gravity	3.11	2.63	2.66
Water absorption (%)		3	0.3
Loose Bulk density (kg/m^3)	-	1484	1446

The fineness of the cement used in this study was 8.3 %. This is less than the maximum 10 % specified by BS EN 196-6 (2016). In addition, the specific gravity of 3.11 for the cement satisfies the requirement of BS EN 196 (2016). The Fineness modulus of a fine aggregate of 3.76 satisfies the requirement specified in ASTM C136 (2019). The specific gravity of the fine and coarse aggregates meets the requirements of ASTM C128 (2008) and ASTM C127 (2015) respectively. The water absorption capacity of the fine and coarse aggregates is 0.3 % and 3 % respectively. Both satisfy the requirements of BS EN 1097 (2010). The loose bulk density of the fine and coarse aggregates is 1446 kg/m^3 and 1484 kg/m^3 respectively. Both are between 1200 and 1750 kg/m^3, thus satisfying the requirements of ASTM C29 (1997).

3.1 Impact Test Results

Figure 4 illustrates the energy absorption of a concrete specimen with a mix ratio of 1:1:2. The findings indicate a consistent trend in energy absorption for the specimen up to 28 days of curing. Specifically, on the 7th day of curing, the concrete sample containing 2 and 3% fibre exhibited the highest energy absorption of 15 J, indicating superior ductility compared to other specimens. Conversely, the control sample displayed the lowest energy absorption of 13 J, signifying greater brittleness. This pattern persisted on both the 14th day and 28th day, with the concrete sample containing 3% fibre absorbing 18 J and 21 J, respectively. These results highlight that an increase in fibre content enhanced the impact energy of concrete. These results are consistent with the findings of Vivas et al. (2020), who reported that fibre enhances the impact resistance of concrete.

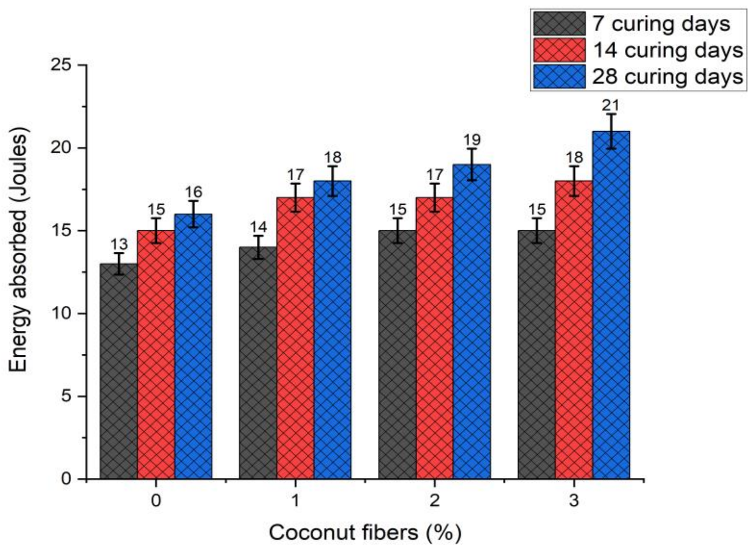

Figure 4: Charpy Impact test result for concrete mix 1:1:2

Figure 5 displays the energy absorption of various specimens with a concrete mix ratio of 1:2:4. In general, there was an improvement in impact energy when fibres were introduced into the concrete. After 7 days of curing, the sample containing 3% coconut fibres absorbed the highest amount of energy at 13 J, while the control sample absorbed the least at 11 J. This trend persisted up to the 28-day mark, with the concrete sample featuring 3% coconut fibre registering 18 J. In comparison to the concrete mix with a ratio of 1:1:2, the specimen with 3% fibre content exhibited lower energy absorption. These results suggest that both the concrete mix ratio and fibre content play a role in determining the energy absorbed. The findings are consistent with Esaker et al. (2023)'s study, which found that increasing the concrete strength or grade enhances the impact resistance of the specimens, a trend observed in our research as well. Similarly, Vivas et al. (2020) reported that higher fibre dosage improves the impact resistance of concrete. This was also evident in our study, where the highest strength was achieved with a 3% fibre dosage.

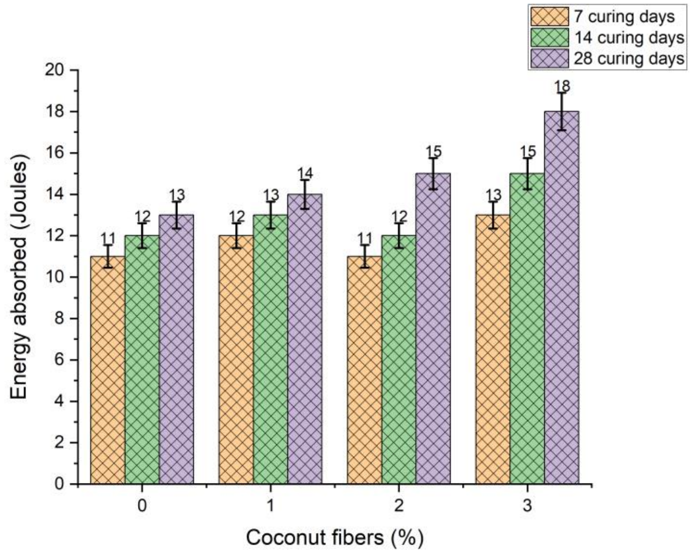

Figure 5: Charpy Impact test result for concrete mix 1:2:4

4.0 CONCLUSION

This study looked into the impact resistance of two different mixes of coconut fibre-reinforced concrete. The following conclusions were drawn from the study:

1. The introduction of coconut fibre into the concrete matrix demonstrated a significant improvement in its impact resistance.
2. The most effective impact resistance for concrete mix 1:1:2 was noted when incorporating 3% coconut fibre. This underscores the crucial role of this particular fibre dosage in improving the material's ability to withstand impact loads.
3. In the case of concrete mix 1:2:4, the ideal proportion for maximizing impact resistance was identified as a 3% incorporation of coconut fibre, underscoring the dosage dependency of the fibre's effectiveness in enhancing impact resistance.
4. Concrete samples characterized by a mix ratio of 1:1:2 exhibited a higher capacity for energy absorption compared to their counterparts with a mix ratio of 1:2:4, emphasizing the influence of mix proportions on the impact energy absorption capabilities of the reinforced concrete.

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