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Analysing the Impact and Investigating Coconut Shell Fiber Reinforced Concrete (CSFRC) under Varied Loading Conditions

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ABSTRACT

This experimental study focuses on analyzing the compositional characteristics of Coconut Shell Fiber-Reinforced Concrete (CSFRC) under varying impact loading conditions. To conduct the experiments, a specially designed falling weight hammer system was utilized to apply cyclic impact loads to both one-time and recurrently tested specimens. The study evaluated two types of specimens: plain Cement Concrete (PCC) and CSFRC, with dimensions of 150 mm in diameter and 300 mm in height for larger specimens and 100 mm in diameter and 150 mm in height for smaller ones. The impact testing involved subjecting these specimens to critical impact load energies using a drop hammering impact load test. Several parameters, including impact pressure, elastic modulus exchange, and the dynamic instability factor (DIF) of CSFRC, were studied during a single load impact test. Through a series of impact tests, the study established a correlation between the maximum compressive stresses experienced and the significant damage caused by the impact loading. It was observed that the maximum critical impact stress levels were linked to the peaks in impact loading, leading to a conclusive finding. This study also focuses on investigating the behavior of Coconut Shell Fiber Reinforced Concrete (CSFRC) under diverse loading conditions. To assess the performance of CSFRC, we subjected specimens to varying types and levels of loading. These specimens, along with plain Cement Concrete (PCC) reference samples, were prepared in two different sizes: 150 mm in diameter and 300 mm in height for larger specimens and 100 mm in diameter and 150 mm in height for smaller ones. The impact testing involved exposing the CSFRC specimens to critical impact load energies using a drop hammering impact load test. Throughout these tests, we examined impact pressure, elastic modulus exchange, and the dynamic response represented by the dynamic increase factor (DIF) specific to CSFRC. Furthermore, we conducted a comparative analysis to assess and contrast the primary failure modes and risks associated with PCC and CSFRC samples under varying loading conditions. Through a series of rigorous impact tests, we established a conclusive relationship between the maximum compressive stresses reached and the extent of damage incurred due to the impact loading. Our findings illuminate how CSFRC behaves and responds to different loading conditions, shedding light on its suitability for various applications in construction and engineering.

Keywords:
Coconut shell fiber; reinforced concrete; dynamic instability factor

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1. Introduction

Coir Fibre-Reinforced Concrete's performance and technical requirements have gained more attention in recent years. Natural fibres such as flax, hemp, jute matrix, and linen are effective when used with reinforced concrete to withstand static stresses [1-6]. Real-world buildings, however, are regularly subjected to dynamic loadings, such as those caused by earthquakes, automobiles, aeroplanes, and even explosive strikes. This highlights the need of studying fibre reinforcement concrete with critical impact loads. Research on the critical impact of concrete materials and Coir fibre-reinforced concrete composites in their different forms have been undertaken [7-9]. The modern drop weight impact test for cement concrete beams was developed by Solemani and Banthia *et al.*, [8]. Varying loading caps may be attached to the top of each load cell to achieve different load capacities (concentrated load, linear load and surface load). Mindess and Bentur [9] analysed the fractured toughness of Plain Cement Concrete (PCC), Steel Fibre Reinforced Concrete (SFRC), and Glass Fibre-Reinforced Concrete (GFRC) using photographic records (GFRC). The findings showed that the cracking process under static loading was not drastically different from that under critical impact loading. Destructive impact testing of SFRC was conducted by Wang *et al.*, [10], and they found that the steel fibre content was the most important factor influencing the response of SFRC buildings. Yazici [11] looked at how SFRC held up under a decreasing weight load to determine its strength qualities. The critical impact fracture energy and the loss of mechanical characteristics were calculated by a series of drop weight measurements. He found that the impact resistance of SFRC was much higher than that of non-fibrous concrete. Xu *et al.*, [12] investigated the effect of impact loading on the tensile characteristics of spiral steel fibre reinforced concrete. Dynamic splitting experiments were performed to measure fracture energy and obtain dynamic tensile strengths. The results confirmed the superior impact resistance of the concrete strengthened with spiral steel fibres. When used in conjunction with polypropylene fibre, concrete shrinkage cracking may be successfully mitigated [13]. According to Nili and Afroughsabet's [14] investigation on the impact resistance of concrete, polypropylene fiber-reinforced concrete structures exhibited ductile failure under impact loading while significantly improving energy absorption. Polyolefin fibre-reinforced concrete absorbed the least amount of energy compared to steel, VPA, and unreinforced concrete. Ong *et al.*, [14] and Badr *et al.*, [16] employed drop weight effect testing and statistical analysis to investigate the impact resistance of polypropylene fibre-reinforced concrete. Results indicated that at least 40 samples were required for trustworthy statistical analysis.

Concrete is one of the most widely used construction materials globally, owing to its durability and strength. In recent years, there has been a growing interest in enhancing the performance of concrete through the incorporation of various additives and reinforcements. One such innovative approach is the utilization of natural fibers, such as coconut shell fibers, to reinforce concrete, resulting in what is known as Coconut Shell Fiber Reinforced Concrete (CSFRC).

Coconut shell fibers are a renewable and sustainable resource, making them an attractive choice for reinforcing concrete. Their integration into the concrete matrix can potentially enhance several crucial properties, including tensile strength, toughness, and crack resistance. However, the behavior of CSFRC under different loading conditions, particularly under impact or cyclic loading, remains a subject of active research and investigation.

Researchers have used both analytical and numerical methods to study the critical impact peculiar to concrete buildings. Habel and Gauvreau [17] conducted experiments on super high performance fiber-reinforced concrete. They also employed random mass-lent models to examine the effectiveness of the impacts. There was excellent agreement between the results of the experiments and the model summary. Natural fibres have grown in popularity because of their low cost, little impact on the environment, and durability.

Static loading conditions have been used in a number of studies on natural fiber-reinforced concrete. For instance, Chen and Chouw [18, 19] showed that the inner flax fibre-reinforced polymer (FFRP) tube may replace the decreased use of Coconut Fibre-Reinforced Concrete (CFRC), and that weight reductions of double FFRP tube limit CFRC parts have no negative impact on the bending hardness. Natural fibre concrete's resistance to impact effects hasn't been the subject of numerous investigations [20].

Wang *et al*., [21] conducted impact studies on hybrid concrete slabs reinforced with steel and bamboo fibres, and found that the hybrid fibre slab exhibited high impact resistance even after initial breaking. Additional research on natural fibres was done by Ramakrishna and Sundararajan [22]. The coir fibre slab performed best when impact loads were given to reinforced slabs manufactured from four different natural fibres: coir, sisal's, jute matrix, and hibiscus cannebinu. The coir fibre slab outperformed the sisal fibre slab, the jute fibre slab, and the hibiscus cannebinus fibre slab when impact loads were applied to the slabs as reinforcement.

Insights into the properties and behaviour of Coconut Shell Coir Fibre-Reinforced Concrete (CSFRC) under different impact loading circumstances are provided by this experimental study effort, making it of great value. This investigation provides insight into the structural performance and durability of CSFRC by submitting specimens to cyclic impact stress using a drop weight hammer instrument. The advantages of CSFRC may be evaluated by comparisons with standard Cement Concrete (PCC) specimens in the trials done. Parameters of CSFRC such as impact force, elastic modulus changes, and forceful growth factor (DIF) are investigated, and essential damage patterns and their differences between PCC and CSFRC are uncovered. Furthermore, this research provides useful insights that may direct the design and execution of CSFRC in real-world building situations by studying the impact loading height's effect on compressive stresses and critical damage. In the end, the results help us better understand how CSFRC may be used in structural applications and how it can improve the durability and functionality of concrete buildings.

Composites made of fiber-reinforced concrete (CSFRC) have not, to the authors' knowledge, had their impact on behaviour studied. The primary goal of this research is to understand how CSFRC composites respond to both single and repeated drop weight impact loadings. The dynamic increase factor (DIF) of CSFRC, the evolution of the critical impact force, and the change in Young's modulus were all studied in the single impact test. The damage patterns of PCC and CSFRC were compared in the proposed investigation. In a series of repeated drop weight hammer experiments, the effect of impact height on maximum compressive stress and damage pattern was evaluated. The relationship between impact height and peak impact stress was suggested using an experimentally derived equation.

This study seeks to contribute to the understanding of CSFRC's performance by conducting a comprehensive analysis of its response to varied loading conditions. Through systematic experiments involving cyclic and critical impact loading, we aim to evaluate the mechanical and dynamic characteristics of CSFRC specimens in comparison to traditional plain Cement Concrete (PCC) samples.

The findings of this research have the potential to not only shed light on the structural and mechanical properties of CSFRC but also to provide valuable insights into its suitability for various engineering and construction applications. Additionally, the environmentally friendly aspects of utilizing natural fibers in concrete reinforcement align with the growing emphasis on sustainable and eco-conscious construction practices.

In the following sections, we will delve into the experimental methodology, results, and discussions, aiming to advance our knowledge of CSFRC's behavior under diverse loading conditions and its role in the realm of modern construction materials.

2. Methodology

a. Raw Materials

Cement, fine aggregate, gravel, water, and brown coconut fibres sourced from Coimbatore make up the rest of the CSFRC composite specimens. The gravel is between 9 and 16 mm in size. The fine aggregate was river sand that was verified to be from Zone II. Coconut fibres average 0.35 mm in diameter. During preparation, the coir fibres were cut to their final length and the dust particles were removed. Figures 1 and 2 depict a flowchart that was inspired by Ali *et al.*, [23]'s description of the steps involved in processing coconut fibre. The experimental properties of sand, gravel, and coconut coir fibre are listed in Table 1.

Fig. 1. Coconut Fibre

Fig. 2. Coconut with minimal Fibre

Table 1
Possible test performed on Aggregates

Aggregate Test	Possible Test Carryout [Yes / No]				
	Aggregate Class / Grades				
	Naturally		Recycles		
	Granular Material	Sand	Coarse		Fine
	>5mm & <20mm	<5mm	>20mm	>5mm & <20mm	<5mm
Water Content	P	P	P	P	P
Relative Density	P	P	P	P	P
Water Absorb value	P	P	P	P	P
Particle Size Class	P	P	P	P	P

Table 2
Possible test performed on Coconut Coir's

Coconut Coir Test	Possible Test Performed [Yes / No]				
	Aggregate Type / Grades				
	Natural		Recycles		
Water Content	P	P	P	P	P
Relative Density	P	P	P	P	P
Water Absorb value	P	P	P	P	P
Particle Size Class	P	P	P	P	P

b. Preparation of specimens

The experimental concretes were composed of either plain cement concrete (PCC), coconut coir shell fiber-reinforced concrete, or both. Each concrete type had a predetermined compressive strength of 30 MPa (CSFRC). The cement:water:fine-sand mass ratio for standard concrete is 1:0.48:2. UltraTech cement's Pozzolana Portland cement was utilised. Coconut coir-fibres accounted for 1.6% of the cement weight, or around 0.7% of the total volume of coir fibre. Each fibre measured in at 50 mm. Aside from the addition of coir-fibres and the elimination of an equivalent amount of course aggregate, the design of CSFRC was similar to that of ordinary cement concrete. The exact CSFRC mixture ratios were listed in Table 3. All of the samples were cured in the concrete cure chamber for 28 and 56 days prior to testing.

In order to create both PCC and CSFRC, we used a concrete mixer. The concrete materials were placed in a drum and rotated for 3 minutes to mix. Droop cone tests revealed an average slump of around 40 millimetres. Before casting CSFRC composites, the coconut coir-fibres were equally divided using the wet lay-up procedure. A layer of sand, coir-fibres, and cement is initially applied to the container's inside. This step is continued until all of the ingredients have been put to the mixing pan. A 90-second spin cycle is then applied to the mixture. Two more minutes were added to the spinning time after half of the percentage of water was added. As it is, the CSFRC is useless. The last bit of water is added to the mixture on the tray to guarantee a thorough mix and even distribution of ingredients. Then, for the next minute and a half, the mixture is spun at high speed. About 45 millimetres was the average for slump tests. Cylinders of 150 mm in diameter and 100 mm in height were produced for both PCC and CSFRC. At least three samples of whatever was being tested were gathered.

Table 3
Mechanical Properties of Raw Materials

Materials	Dry Density [Kg/m3]	Length(L) [mm]	Dia # [micron]	Tensile Strength [N/mm^2]	Elastic Modulus [Gpa]	Elongation at break [%]	Moisture Content [%]	Water Absorption [%]	Fineness Modulus
Coir	1.24	20-150	100-130	130-245	5-7	18-22	-	160	-
River Sand	1650	-	0.06	-	0.089	-	5.8	-	2.84
Coarse Aggregate	1540	-	22.4	-	-	-			

3. Experimental Investigation

3.1 Testing of Static Condition

In all, twelve cylinders were tested. There were a total of six samples used, three of which were PCC cylinders and the other three were CSFRC specimens with 25, 50, and 75 millimetres of coconut coir-fibre (CSFRC-25, CSFRC-50, and CSFRC-75, respectively) (CSFRC-75). These specimens were put through a compressive test equipment to determine their specific crushing strengths and static moduli of elastic limit. Each cylinder was capped with plaster before being subjected to compression testing to ensure that the force was distributed uniformly. All tests were performed in accordance with the ASTM C39/C39M Standard [24].

3.2 Impact Test on Specimen

An explanation of how a drop weight impact machine works. In Figure 3, we can see the drop weight of the impact machine, which is specified in the text. The impact device's mechanical construction has a data storing system. The mechanical framework consists of a steel framework, guiding element, chain block, and magnetic system. The floor is one metre thick and made of solid concrete that is prestressed onto a steel framework. The steel building is four metres in height. A chain hoist is used to elevate the descending weight to the various impact heights. A magnetic device operated by remote holds the descending weight in place until the operator releases it. The impact tests have a negligible effect on the facilities holding the impact machine. This is due to the fact that there is no structural link between the sturdy floor it rests on and the remainder of the structure. A rubber surface was added to the strong floor around the impact machine to ensure that the stresses sent to the floor were distributed as evenly as possible. The test rig relies heavily on a free-falling hammer that may be dropped from a maximum height of 2.5 metres. Impact masses may vary from 30 kg to 200 kg in 10 kg increments.

Fig. 3. The drop weight impact machine is shown in a systematic diagram

Table 4
The compositions of mixture ratio

Specimen identification	W/c Ratio	Content of Cement (Kg /m^3)	Fine Sand (Kg /m^3)	Course Sand (Kg /m^3)	Value of Slump [mm]
PCC	0.46	434	866	1734	42
CSFRC - 10	0.54	421	846	1696	41
CSFRC - 30	0.54	421	846	1696	38
CSFRC- 60	0.54	421	846	1696	38
CSFRC - 90	0.54	421	846	1696	37

3.Results

3.1 Pressure Distribution

3.1.1 Loading cell

Impact strength is evaluated via a piezoelectric force sensor (Model 200 C50, PCB Piezotronics). The greatest value that may be measured is 333 kN. The sensors were also calibrated by PCB Piezotronics, and their precision is 0.7N.

3.1.2 Dropping weight hammer test procedure

The following test was conducted on CSFRC cylinders using a falling weight study. After the specimens were prepared, strain gauges were attached to them. The dynamic load cell was installed on the solid floor, and the specimen was placed on top of it. The load sensor and strain gauges were then wired up to the data logger system. The 40 kg impact amount is lifted to the desired height and then released in order to hit a specimen. In the impact test, just one drop was utilised, but in subsequent tests, multiple drops were employed.

4. Findings and analysis of Results

4.1 Test for static compression

The compressive strengths and elasticity moduli of PC and CSFRC are listed in Table. 5

Table 5
Compressive Strength & Modulus of Elasticity

Specimen Type	Fibre Length [mm]	Modulus of Elasticity [Mpa]	Compressive Strength [Mpa]
PCC	-	32.8×10^3	33.09
CSFRC - 10	10	31.9×10^3	33.64
CSFRC - 30	30	32.3×10^3	33.25
CSFRC - 60	60	32.8×10^3	32.94
CSFRC - 90	90	31.6×10^3	32.16

4.2 Results of a single impact test

4.2.1 Single impact force results (Time History)

This section analysed the beginning and ending Elastic modulus changes caused by impact loading. Costs for PCC and CSFRC up to 60 mm fibre were analysed using the proposed methodology (CSFRC-60). Three different heights (50 cm, 100 cm, and 150 cm) were considered in this series of tests. Significant deformation of the specimens was seen when the falling height was more than 1000 mm and elastic deformation occurred to a lesser extent than 1000 mm. The consideration of drop height is unique to this paragraph. The load cell reading represents the impact force. By dividing the largest impact force by the cross-sectional area, the maximum impact stress may be determined. Figure 4 depicts the PCC, CSFRC-60's impact force history. For around 0.004 seconds, both types of cylinders were subjected to collisions.

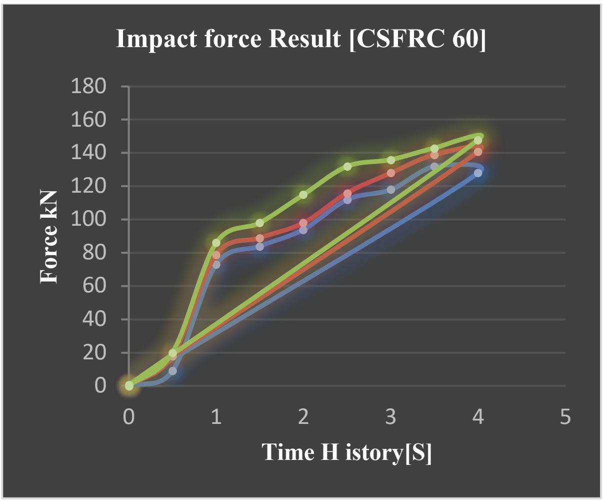

Fig. 4. Force to time history graph

Table 6
Elastic modulus initial and final impact loadings are compared

Specimen Class	Impact Depth [cm]	Elastic Modulus initial impact [E_0 in GPa]	Elastic Modulus final impact [E_o in GPa]	Damaged Value [$E_0 – E_1 / E_0$] %
PCC	50	37.89 [0.89]	33.80 [0.65]	10.79
PCC	100	37.89 [0.89]	32.45 [0.89]	14.36
CSFRC - 60	50	38.81 [0.91]	36.92 [0.82]	4.87
CSFRC - 60	100	38.81[0.91]	35.42 [0.76]	8.73

4.2.2 Elastic moduli of PCC and CSFRC cylinders calculated by the impact loading

Material properties such as moduli of elasticity and strength are often used to harm materials. This article used moduli of elasticity to explore the damage situation under falling weight loading. The D-Index of Damage is Defined.

$$D = {}^{\partial E}/_{Eo} \tag{1}$$

where ∂E = E_0 –E_1 represents the alteration in elasticity moduli due to impact, E0 stands for the actual elasticity moduli of the shattered concrete cylinder as established by static compressive testing, and E1 stands for the elasticity moduli of the cylinders that have been impacted by the free falling mass. Young's moduli are the secant modulus at a stress level equal to one-third the failure stress.

Impact loads from drops of 500 mm and 1000 mm are shown on the CSFRC-60 specimens and the PCC damage index in Table 6. As a consequence, the elastic moduli were found to be reduced for both sample types. When dropped from 50 and 100 centimetres, the PCC samples lost 8.73 and 4.83 percent of their elastic modulus, respectively. Young's moduli also decreased by about the same amount (14.36% for drops less than 50 cm and 10.79% for decreases less than 100 cm) in the CSFRC-60 samples.

However, it was found that the damage patterns for these two materials were quite different. The PCC and the CSFRC samples seemed unharmed after being dropped from a height of 50 centimetres. When impact heights of 100 cm and 150 cm were applied, however, the specimens' exteriors were clearly damaged. In Fig. 6, we can see the effects of impacts from 100 cm and 150 cm on PCC and CSFRC-60 specimens. Small-scale spalling and cracks appeared in the PCC specimen after it was dropped from a height of 100 centimetres. The CSFRC-60 specimen sustained very little damage. A few chunks of concrete flew off with the force of the fall from a height of 100 cm, causing face cracks around 3 cm in length. For the same 150 cm of impact, the CSFRC-60 specimen was less severely damaged than the PCC specimen. Large fractures and significant spalling in the PCC cylinder reduced the surface area in contact. However, the CSFRC-60 sustained a single face fracture about 50 cm in length and some minor spalling from the 150 cm impact. It is hypothesised that the reduced damage experienced by the PCC specimens is due to the incorporation of coconut shell fibre into CSFRC-60. Coconut fibres were sprinkled over the CSFRC-60 samples to reduce spalling and limit the spread of cracks.

4.2.3 CSFRC's factor for dynamic increase (DIF)

In Impact loading has a distinct effect on concrete's compressive strength compared to static stress. Previous studies employed a Dynamic Increase Flow (DIF) as a metric to analyse the effect of impact loading on compressive strength. This section tested the DIF of CSFRC when subjected to impact loads to determine how much of a toll impact had on the strength of CSFRC composite parts. The adopted drop was 50 kg and 2 m in height.

Compression strength during impact loading was divided by static compression strength to get the DIF. The CSFRC DIF was predicted using both the DIF and the European-International Committee for Concrete's (CEB) methodology [25]. The following formula determines the DIF for compression testing according to the CEB model

$$DIF = {}^{fcd}/_{fcs} \tag{2}$$

where

f_{cd} = Compressive Strength in Dynamic, f_{cs}= Compressive Strength in Static

The strain rate is calculated by dividing the time required to achieve a maximum symmetrical strain by the strain itself [26]. Study DIF and empirical formula results are shown in Table 7. There is a significant gap between the static and impact compressive strengths of concrete. The results of the studies indicate that the DIF is around 1.2.

So, concrete is far more sturdy against impact loads than it is against static ones. This is the situation as a result of preoccupation with strain rate. The strain rate caused by static loading is about 6.2 x 105 S-1, whereas the strain rate caused by impact loading is approximately 2 s-1. This finding is generally in agreement with the findings of other studies. At strain rates between 1.5 and 11 S-1, Pajak [27], who investigated the impact of strain rate on concrete's compression strength, discovered that the DIF values were between 1 and 2.

Since the impact behaviour of natural fiber-reinforced concrete is not dissimilar to that of regular concrete, it is not surprising that the two materials have many similarities. Drop weight loading had no influence on the behaviour of CSFRC composites, as seen by the lack of variance in compression strength values between CSFRC samples. To calculate the strain rate, divide the strain by the time it takes to attain a maximum symmetrical strain [26]. Study DIF and empirical formula results are shown in Table 7. There is a significant gap between the static and impact compressive strengths of concrete. The results indicate a DIF of around 1.2.

4.2.4 Impact over time: Test findings

Testing on CSFRC-10, CSFRC-30, CSFRC-60, and CSFRC-90 specimens underwent continuous impact, and the findings are described below. The 40 kg drop weight was employed in the repeated trials. Nonetheless, we employed a range of drop heights, increasing the heights until we saw significant crushing damage to the samples. You may calculate the impact failure energy using the following expression:

$$W = P\ (h1 + h2 + \cdots . + hn) \tag{3}$$

The failure energy impacts are denoted by W, the falling weight is 354 N, the first drop height is denoted by h1 (50 cm), the second drop height is denoted by h2, and the final drop height is denoted by hn.

Fig. 6. Impact loading

Fig. 7. Coired Concrete - Cylinder Specimens

Table 7
DIF results for CSFRC that are calculated]

	CSFRC 10	CSFRC 30	CSFRC 60	CSFRC 90
Compressive Strength under Static [MPa]	34.72	32.46	31.74	29.78
Strain Rate [10-5 S-1]	4.76	5.16	5.23	5.08
Compressive Strength under Dynamic [MPa]	39.64	38.71	37.84	36.69
Impact test strain rate [S-1]	1.64	1.75	1.98	1.81
DIF based on Experiment	1.24	1.18	1.29	1.32
DIF base on Calculation	1.45	1.39	1.36	1.28

The impact failure energy is W, P is the 354 N drop weight, h_1 is the initial drop height (60 cm), h_2 is equal to h1, and h_n is the dropping height corresponding to last experiment number, where $h_n = nh_1$.

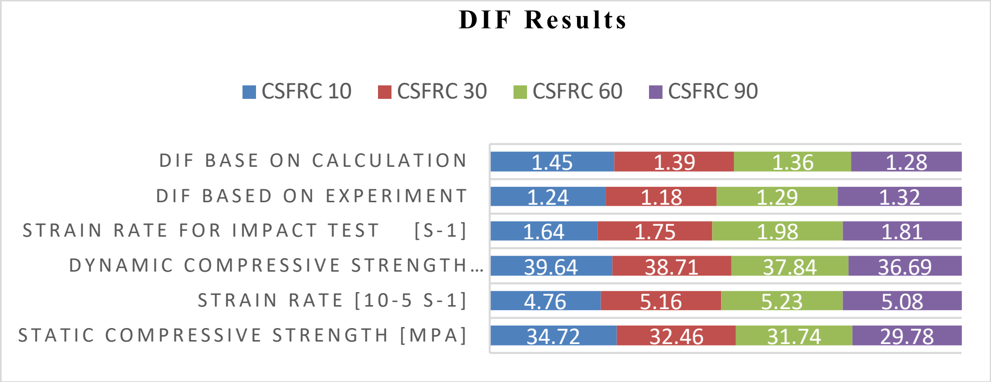

Fig. 8. DIF Results for CSFRC

4.2.5 The force of impact over time

CSFRC-10, CSFRC-30, CSFRC-60, and CSFRC-90 impact history under cyclic loadings are shown in Figure 8. Approximately 0.006 seconds passed between the beginning of the collision and the moment when the whole impact force was felt. Time to cap value was explained in the same way as Figure 5, which was described in Section 3.2.1. Crushing required a different number of blows for each specimen type. The CSFRC-30 and CSFRC-60 specimens were crushed after receiving four blows from the drop weight. Crushing occurs at an impact height of 150 centimetres. On the other hand, the CSFRC-90 test specimens may have been crushed with as few as three blows, implying an impact distance of up to 150 cm.

Table 8 summarises, for a range of drop heights, the maximum impact pressures, stresses, and strains. The maximum impact force values were 164.5 kN for CSFRC-10, 176 kN for CSFRC-30, 153.9 kN for CSFRC-60, and 154.6 kN for CSFRC-90. When falling from a height of less than 100 cm, the impact force of the CSFRC-30 and CSFRC-60 rose linearly with the increase in dropping height. When comparing the impact forces created by drop weights of 100 cm and 150 cm, it was discovered that they were comparable. Damages were shown to materialise in the samples, hence this experiment makes sense.

Both the CSFRC-30 mm and CSFRC-60 mm specimens showed quite similar connections between compression strength and falling height. For drops of 30 cm, 60 cm, and 90 cm, the highest stresses were recorded as 13.1 MPa for 1000 mm drops, and as 24.06 MPa for 1500 mm drops. The stress applied at the last impact (h = 90 cm) was sufficient to fracture the specimen; its maximum stress was quite similar to that of the third impact. However, the CSFRC-90 was destroyed in the third collision. For the CSFRC-30 and CSFRC-60, an equation was developed to approximate the test results between impact height and maximum impact stress.

Table 8
Summary of repeated impact test results.

Fibre Length(mm)	Height (mm)	Impact Energy(Nm)	Impact Force(kN)	Maximum Stress (MPa)	Maximum Strain (µ)
10	50	146.12	85.32	8.5	154
	100	224.67	98.45	9.6	286
	150	395.14	145.67	12.3	467
30	50	148.15	81.56	7.6	198
	100	223	97.45	8.4	324
	150	401.18	139.34	11.65	761
60	50	149.87	89.23	8.1	225
	100	218.65	104.26	9.6	407
	150	385.5	139.78	12.87	789
90	50	148.16	82.0	9.13	245
	100	229.65	110.67	11.54	468
	150	395.34	146.45	13.56	849

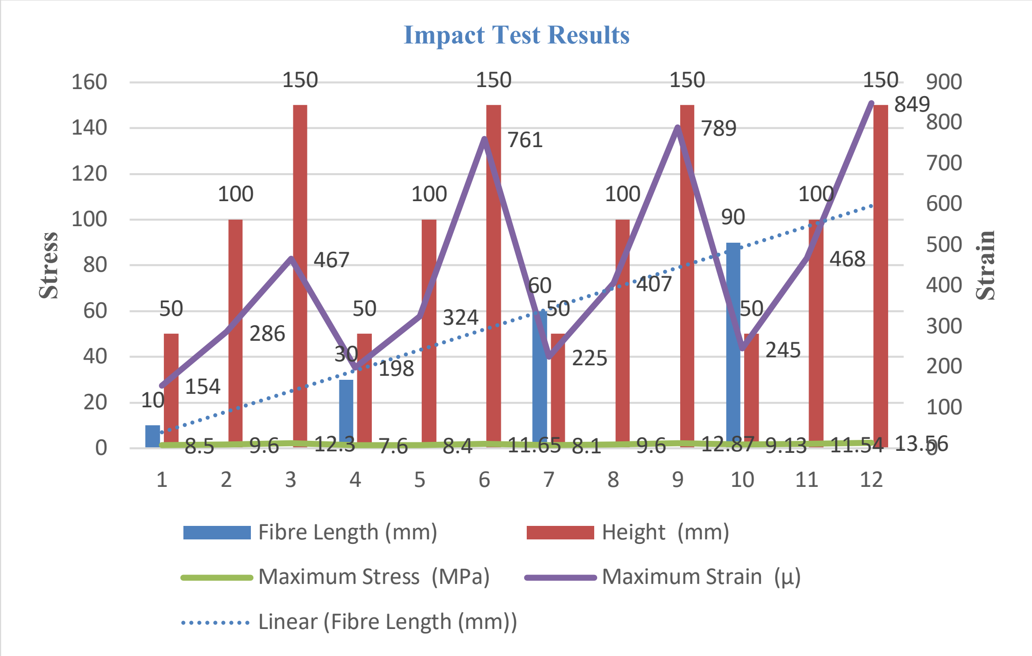

Fig. 9. Impact Test Results

The research found that CSFRC was superior than ordinary Cement Concrete in terms of Mechanical Performance (PCC). Its tensile, flexural, and fracture resistance were all significantly improved. The strengthening impact of coconut shell fibres inside the concrete matrix is responsible for these enhancements.

Load-Deflection Behavior: CSFRC showed better resilience and ductility than PCC under cyclic loading circumstances. Its capacity to bend and absorb energy in this way indicates that it will not collapse catastrophically. A more progressive and regulated reaction, as shown in the load-deflection curves, is preferable in structural applications.

Impact Resistance: When exposed to critical impact loads, CSFRC showed reduced damage and spalling, indicating increased impact resistance. This demonstrates the ability for CSFRC to sustain abrupt dynamic loads, making it appropriate for applications where impact resistance is critical, such as pavements and structures in seismically active locations.

The research determined the CSFRC's dynamic response by calculating its dynamic increase factor (DIF). To evaluate the material's response to dynamic loading circumstances and to incorporate this knowledge into the design of structures exposed to impact or cyclic loads, knowledge of the DIF is crucial.

Benefits to the Environment and Sustainability: Reinforcing concrete using fibres extracted from coconut shells is an example of green building. The importance of using renewable and biodegradable materials in construction is emphasised in the research, as is the eco-friendliness of CSFRC.

Pragmatic Applications: CSFRC shows potential in a number of engineering applications, including as structural components, pavements, and earthquake-resistant buildings. It may be used as an alternative to conventional concrete because of its enhanced mechanical qualities and impact resistance, which might result in stronger and more environmentally friendly buildings.

Overall, the mechanical behaviour and performance of CSFRC under varying loading situations are thoroughly analysed and discussed in the comments section. This research highlights concrete's potential as a long-lasting and environmentally friendly building material, providing useful information for concrete technology innovators in the engineering and research communities.

5. Conclusion

In summary, the results of this experimental study of Coconut Shell Coir Fibre-Reinforced Concrete (CSFRC) have revealed important information on the material's response to impact loading. The research shows that CSFRC has the potential to replace PCC in many building settings. The structural performance of CSFRC has been better understood by analysing several metrics like impact force, elastic modulus variations, and critical damage patterns. The results of this study show that CSFRC is superior than PCC in its resistance to impact loading, suggesting it will be a more durable and resilient building material in the field. Exploring how impact loading height affects compressive stresses is also relevant to improving CSFRC design. In conclusion, the findings of this study expand our understanding of CSFRC, paving the way for its use in environmentally friendly, high-performance concrete buildings and boosting the overall area of construction materials science.

Scientists conducted experiments to see how falling weights will affect cylinder samples made of coconut coir shell fiber-reinforced concrete (CSFRC). Impacts from as little as 50 centimetres on the CSFRC specimens were enough to cause internal damage, as measured by a drop in tensile modulus. The DIF of CSFRC was not significantly changed by fibre length in the coconut shell, according to the study data. Coconut shell fibre inclusion revealed the same behaviour as plain concrete under compressive dynamic strength tests. Nonetheless, CSFRC fared better in terms of resist spalling with fragmentation thanks to the dispersion of coconut shell fibre's bridge function. It is helpful to shield people from falling debris in damaged buildings.

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