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Influence of Partial Replacement of Cement with Waste Materials on Mechanical Properties of Concrete

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KEYWORDS

Coconut fibre ash, Glass powder, Slump test, Workability, Compressive strength, Tensile strength and Flexural strength, Waste material.

ABSTRACT:

Cement serves a crucial function as a fundamental ingredient in concrete manufacturing. However, over-reliance on cement contributes to adverse environmental consequences. Utilizing locally available waste materials as substitutes for cement holds considerable promise in mitigating environmental impact, particularly within the construction sector, thereby promoting cleaner production practices. The objective of this research is to investigate the effectiveness of replacing cement with coconut fiber ash and glass powder in enhancing specimens performance. Concrete specimens were manufactured using various dosages (i.e., 0, 10, 20, 30, 40, 50, 60, 70, and 80%) of coconut fibre ash and 0, 10, 20 and 30% of glass powder. To evaluate the performance of these concrete specimens, a series of tests including compressive strength, split tensile strength, and flexural strength were conducted across various combinations of coconut fiber ash and glass powder percentages. The concrete specimens underwent testing at intervals of 7, 14, and 28 days to assess their properties. Partial substitution of waste materials is used in concrete along with cement is conducted with the goal of attaining desired concrete properties such as strength, durability, and workability. The results of all tests revealed that, maximum strength were achieved at 20% of coconut fibre ash and 10% of glass powder.

1. Introduction

1.1 General:

Concrete, an essential component in constructing infrastructure and development projects, holds promise for significant and beneficial environmental impact. Waste materials in concrete can be utilized as substitutes for cement or aggregate, as well as fillers or fibers. Considering the environmental risks associated with cement, employing waste materials as replacements for cement is a feasible alternative. The environmental benefits of substituting waste material for cement can be explored through two approaches. One method involves reducing the portion of cement in concrete, while the other entails utilizing waste material that holds no utility in concrete. Due to the extensive global consumption of cement, a significant amount of waste material can be utilized as a substitute for concrete. In the context of minimizing cement usage, employing pozzolanas offers numerous advantages, including the decrease in greenhouse gas emissions, particularly those of carbon dioxide and nitrogen oxides, which are among the most harmful pollutants.

During the period of 2022-23, India consumed 373.1 million tons of cement. If some percentage of construction projects in our country incorporated waste materials as substitutes for cement, a substantial amount of the waste produced in India could be repurposed within a year. This would conserve the nation's other resources while simultaneously decreasing environmental pollution within the country. Hence, utilizing waste material as an alternative to cement is advantageous for decreasing both cement usage and waste generation.

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1.2 Objectives of Research:

The objectives of research are mentioned below:

- The aim was to lower the cost of concrete by minimizing the quantity of cement utilized in its composition.
- The main objective was to effectively utilize waste materials.
- The study seeks to assess the workability characteristics of M30 grade concrete integrated with coconut fiber ash and glass powder.
- To investigate and contrast the results concerning the compressive strength, split tensile strength, and flexural strength of M30 grade concrete when utilizing coconut fiber ash and glass powder as substitutes, throughout curing durations of 7, 14, and 28 days.
- To fabricate concrete specimens such as cubes, cylinders, and beams, and to analyze the mechanical properties of the concrete.
- To compare conventional concrete with a partially substituted concrete mixture containing coconut fibre ash (ranging from 0 to 80%) and glass powder (ranging from 0 to 30%) in varied proportions.

2. Review of Literature

Dr. Haider, et.al. conducted a study to explore the viability of incorporating waste glass, with a maximum particle size of 5mm, as a replacement for fine aggregate in concrete. They examined various replacement percentages ranging from 10% to 40% for sand. Their results demonstrated that waste glass aggregate could adequately replace natural fine aggregate up to levels of 20%.

Gunalaan Vasudevan, et.al conducted an investigation to examine the impacts of incorporating waste glass powder in concrete. Laboratory experiments were conducted to assess the efficiency of both a control specimen and concrete incorporating recycled waste glass powder. Their findings indicated that, on average, concrete incorporating waste glass powder demonstrated enhanced strength after a 14-day period. However, by the 28th day, the control mixture displayed even higher strength values compared to the blend containing waste glass powder, although both still maintained high values corresponding to the M 30 grade.

P.V.Domke et al. concluded that the strength of concrete increases with a higher percentage of RHA (Rice Husk Ash), and the addition of coconut fiber (CF) helps mitigate the decrease in strength once the optimal strength is reached. Notably, at 7 days, the concrete strength for CF1+RHA9 reaches the highest value at 38.12 N/mm², compared to the control OPC at 28.86 N/mm². Different combinations of CF and RHA yield diverse outcomes, with the maximum strength observed in concrete with a 10% cement replacement, diminishing as the replacement reaches 20%. The findings indicate that the reduction in concrete strength percentage increases with higher levels of CF and RHA replacement.

Olaoye, R.A. et.al. investigated the incorporation of jute, oil palm, and polypropylene fibers as additives in concrete. They evaluated their suitability, durability, and impact on concrete properties. The proportions of fibers used were 0.25 and 0.5 of the cement content by weight. A total of 84 concrete cube samples were produced for standardized evaluations, including compression testing, slump assessment, and compaction factor analysis. They concluded that incorporating jute, oil palm, and polypropylene fibers led to a notable improvement in compressive strength from the 7th to the 28th day, compared to the control mixture.

Ali N. Alzaed. et.al. noted that iron filings are small iron pieces resembling light powder. They employed four different percentages of iron filings added to the concrete mixture to examine potential differences in compression and tensile strengths after 28 days. These percentages included 0% (control), 10%, 20%, and 30%. His conclusion was that incorporating 30% iron filings into the concrete mixture led to a 17% enhancement in compressive strength. The tensile strength of the concrete showed minimal variation when the percentage of iron filings exceeded 10%. The addition of 10% iron filings to the concrete mix resulted in a 13% increase in concrete tensile strength.

Chowdhury et al. employed wood ash obtained from a source of spontaneous combustion of wood properties. The researchers utilized the gathered wood ash to partially substitute cement in concrete mixes. They adjusted the water-to-binder ratio to 0.4 and 0.45. The research included substitution percentages of 5, 10, 15, 18, and 20 percent. The results concerning compressive

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strength, split tensile strength, and flexural strength showed a gradual decline in the load-bearing capacity of concrete with higher wood ash content. Nevertheless, strength was observed to enhance with longer curing durations.

3. Materials and their properties

3.1 Ordinary Portland cement : The cement utilized in all mixtures was Ordinary Portland Cement (OPC) of 53 grade, a commercially available product manufactured by sri chakra cements Pvt. Ltd., adhering to the standards outlined in IS:12269-1987. The physical characteristics of Ordinary Portland Cement are evaluated in accordance with ASTM C 618-78 standards mentioned in below table 1.

Table 1 Physical characteristics of cement

Test	Results
Specific gravity	3.16
Standard consistency	7mm at 34%w/c
Initial and final setting time	40 minutes & 258 minutes
Fineness	4.38%

3.2 Coconut fibre ash: Coconut fibre ash (CFA) was generated through the recycling of indigenous coconut husks obtained from coconut fruits. The fibers were sufficiently dried and incinerated in an open-air environment at temperatures ranging from 600°C to 700°C until they were converted into ash. Afterward, the ash produced was gathered and shifted using a 150-micron sieve. The research involves the incorporation of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% of CFA as a substitute for Ordinary Portland Cement (OPC). Table 2 displays the chemical composition of coconut fiber ash.

Fig 1 Coconut fibre ash

Table 2 Chemical composition of coconut fibre ash

Chemical Compound	CFA (%)
SiO_2	16-24
Al_2O_3	3-7
Fe_2O_3	0.4-6.0
CaO	60-67
MgO	0.1- 4.0
K_2O	-
SO_3	1.0-2.0

3.3 Glass powder (GP): Glass powder is defined as finely ground particles of glass, commonly acquired through the process of grinding or milling glass materials. Prior to incorporation into concrete, glass powder must be ground to the desired particle size. It can be utilized as an additional material for cement in particle sizes smaller than 90µm. It performs a crucial role as an additive material in concrete applications because of its fine particle size and pozzolanic characteristics. Glass powder manufactured by SGS India private Ltd has been used in this investigation. The chemical composition of glass powder is provided in Table 3 below.

Fig 2 Glass powder

Table 3 Chemical composition of Glass powder

Parameter	Percentage
Loss on ignition	0.19
SiO_2	70.54
Al_2O_3	0.972
$CaCO_3$	17.53

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Na_2O	13.27
CaO	9.27
MgO	3.89

3.4 Fine aggregate (Natural sand): The fine aggregates employed in this study consist of Penna river sand, passing through a 4.75 mm sieve, and exhibiting a specific gravity of 2.65. According to Indian standard specifications, these fine aggregates are categorized as belonging to grading Zone I. The sieve analysis of natural sand are assessed following the guidelines of IS: 383-1970.

3.5 Coarse aggregate (Gravel): The natural coarse aggregate utilized in this investigation was locally sourced crushed granite aggregate, which adhered to the criteria outlined by IS-383. It passed through a 20 mm sieve and was retained on a 4.75 mm sieve. The coarse aggregate exhibited a specific gravity of 2.7. The sieve analysis of the gravel was examined according to the IS: 383-1970 standards.

3.6 Water: The water utilized for the research was acquired from a naturally flowing stream. It was found to be clear and free from any harmful contaminants.

4. Methodology

The experimental investigation and excavation work were carried out methodically, following a step-by-step approach as outlined below: weighing, mixing, mould Preparation, compaction, curing and testing.

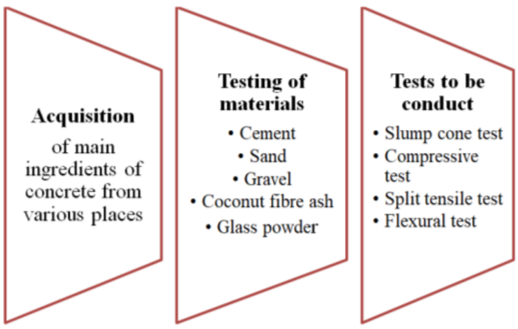

Fig 3 Successive phases of preliminary study

This study examines the characteristics, including compressive strength, tensile strength, and flexural tests, of alternative cement materials such as coconut fiber ash and glass powder. Concrete formulations were created using varying proportions of coconut fiber ash and glass powder. The workability of each formulation was evaluated through the slump test to gauge its workability. The concrete samples were submerged in underwater and subjected to curing for specific durations of 7, 14, and 28 days following their preparation. Subsequent to the curing period, tests for compressive, split tensile, and flexural strength were conducted to assess the concrete's strength. Comparative analyses were conducted with standard concrete samples for evaluation.

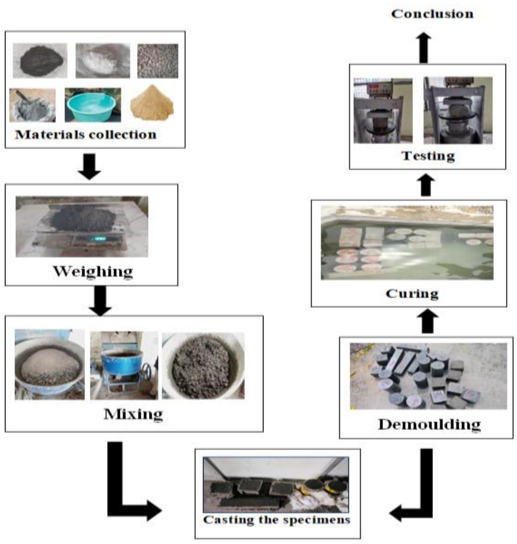

Fig 4 Sequence of the work

5. Mix design

Mix design involves the selection of appropriate components for concrete and establishes their relative proportions to achieve a specified minimum strength and durability in the most cost-effective manner as possible.

The concrete mix design was formulated based on the Indian Standard for conventional concrete. The specified grade was M30. The mixture will be composed of 425 kilograms per cubic meter of cement and a water-cement ratio of 0.5. According to IS 10262-2009, the mix proportion of materials is 1:1.31:2.70. Subsequently, natural fine aggregate was employed. The cement replacement levels with coconut fiber ash ranged from 0% to 80%, while glass powder

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replacements ranged from 0% to 30% in concrete.

6. Result and discussion

6.1 Fresh properties of concrete:

Slump cone test: The slump cone test is carried out to evaluate the workability of concrete, with the observed slump height measuring 30 centimeters. The slumps for the different concretes of coconut fibre ash (0 to 80%) and glass powder (0 to 30%) replacement ranged from 60 mm to 100 mm, according to figure 5. When percentage of coconut fibre ash increases the slump values will be decreases. At a 30% replacement level, the concrete specimen can be categorized as having medium workability. The results indicate that increasing the percentage of replacement with coconut fiber ash (CFA) and glass powder (GP) leads to a decrease in the workability of concrete, as demonstrated in Figure 5 depicting slump values at different percentages of concrete.

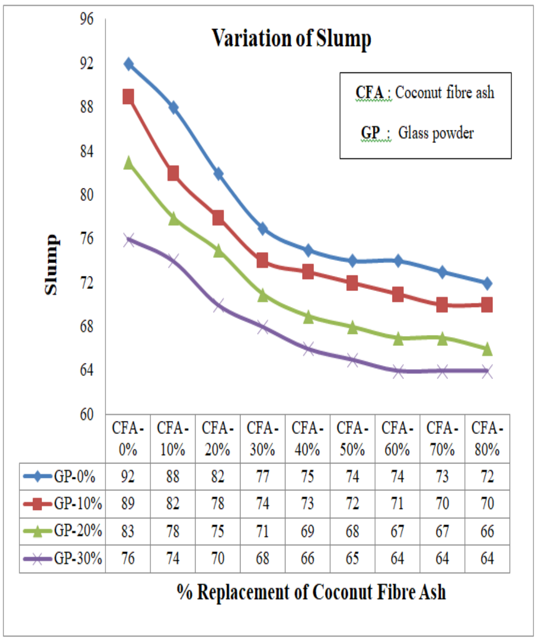

Fig 5 Comparative analysis on the workability of concrete at replacement of coconut fibre ash ranging from 0 to 80% with addition of glass powder from 0 to 30%

6.2 Fresh properties of concrete

Compressive strength test : This section presents and analyzes the outcomes of the compressive strength test conducted on cube specimens of different mixes cured. The assessments were conducted at intervals of 7, 14, and 28 days. Figure 6 illustrates the compressive strength test conducted on a compression testing machine.

Fig 6 Testing on Compression testing machine

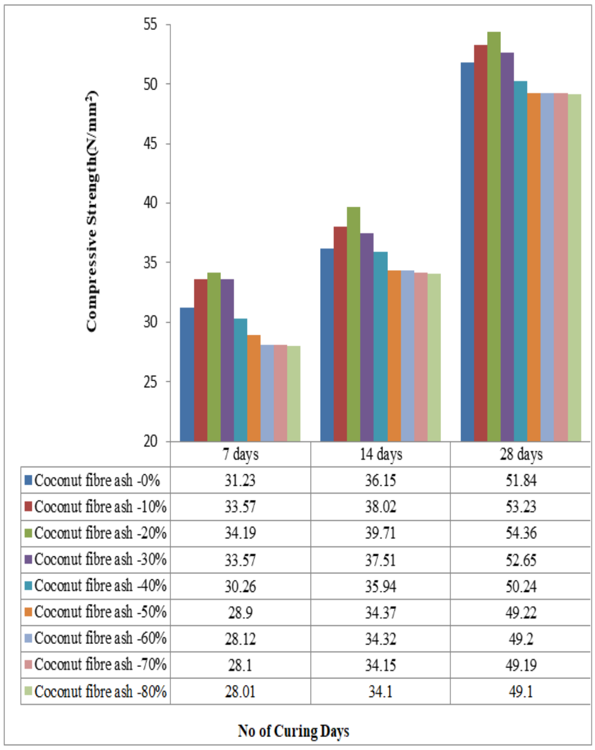

Fig 7 Compressive strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods

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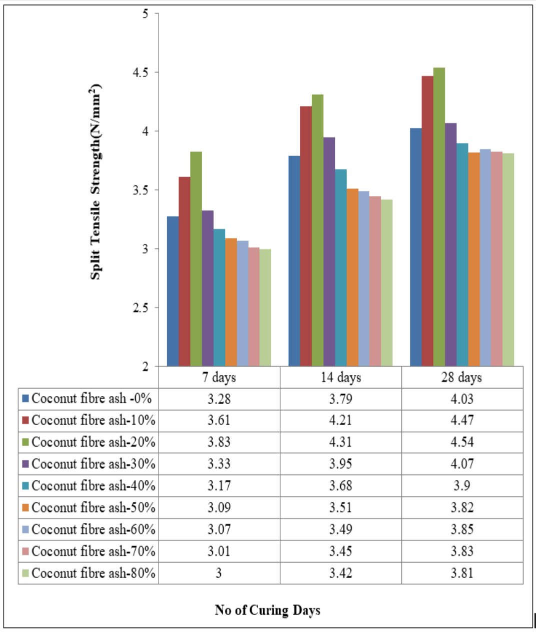
The above figure 7 represents the Compressive strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods. The maximum compressive strength for 28 days occurs at 20% of coconut fibre ash with the addition of 10% glass powder is 34.19 N/mm^2. The compressive strength increases from 0 to 50% replacement of coconut fibre ash. The percentage replacement above 50% will remain constant. As the percentage increases for both the coconut fibre ash and glass powder the compressive strength decreases. The least compressive strength obtained at 80% replacement of coconut fibre ash and 30% addition of glass powder is 23.05 N/mm^2.

The comparison is taken between the %coconut fibre ash from 0 to 80% and 10% glass powder. The 10% of glass powder is choose because the maximum compressive strength obtained at that point. After 10% addition the strength will be decreases. In comparison with normal concrete, 13.95% compressive strength is increasing for conventional concrete. As the number of curing days increases, the compressive strength also increases.

Split tensile strength test: The tensile strength of concrete (tensile stress) refers to its ability to resist breaking under frictional forces, as shown in Figure 8.

Fig 8 Testing of split tensile strength

The figure 9 represents the Split tensile strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods. The maximum Split tensile strength for 28 days occurs at 20% of coconut fibre ash with the addition of 10% glass powder is 4.31 N/mm^2. It shows that 20% coconut fibre ash and 10% of glass powder addition gives reasonable split tensile strength as compared to ordinary concrete. This is because these materials contribute to the production of additional C-S-H(calcium silicate hydrate) gel, which is essential for the structural integrity of concrete. The split tensile strength increases from 0 to 50% replacement of coconut fibre ash. The percentage replacement above 50% will remain constant. The optimum split tensile strength achieved from this mixture is 4.31 N/mm^2, which is 28.52% higher than that of conventional concrete.



	7 days	14 days	28 days
Coconut fibre ash -0%	3.28	3.79	4.03
Coconut fibre ash-10%	3.61	4.21	4.47
Coconut fibre ash-20%	3.83	4.31	4.54
Coconut fibre ash-30%	3.33	3.95	4.07
Coconut fibre ash-40%	3.17	3.68	3.9
Coconut fibre ash-50%	3.09	3.51	3.82
Coconut fibre ash-60%	3.07	3.49	3.85
Coconut fibre ash-70%	3.01	3.45	3.83
Coconut fibre ash-80%	3	3.42	3.81

Fig 9 Split tensile strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods

Flexural strength test: Flexural testing is employed to evaluate the flexural or bending properties of a material.

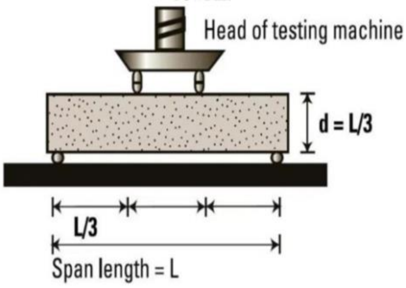


Fig 10 Loading arrangement for determing flexural

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strength test

Fig 11 Beam marking for determining flexural strength test

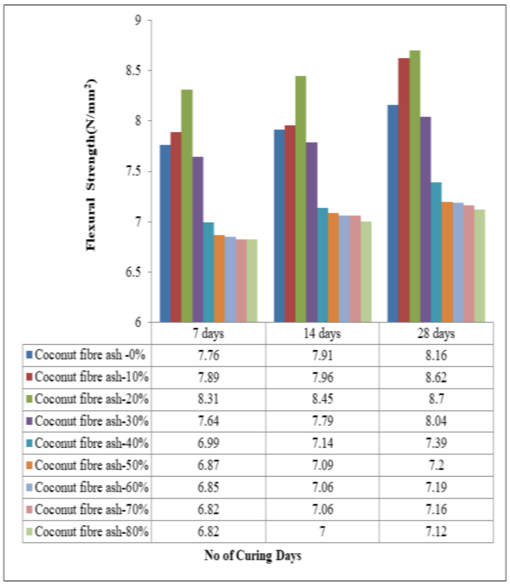

Fig 12 Flexural strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods

The above figure 12 represents the flexural strength at various percentage replacement of coconut fibre ash ranging from 0 to 80% with addition of 10% glass powder during different curing periods. The maximum flexural strength for 28 days occurs at 20% of coconut fibre ash with the addition of 10% glass powder is 8.31 N/mm^2. It shows that 20% coconut fibre ash and 10% of glass powder addition gives reasonable flexural strength as compared to ordinary concrete. The flexural strength increases from 0 to 50% replacement of coconut fibre ash. The percentage replacement above 50% will remain constant. The optimum split tensile strength achieved from this mixture is 8.31 N/mm^2, which is 17.70% higher than that of conventional concrete.

7. Conclusion

In this experimental research, coconut fiber ash and glass powder were utilized as alternative materials for cement in M30 grade concrete. Following various examinations on both fresh and hardened concrete, we have deduced the subsequent findings:

- The combination of pozzolanic reactions, improved particle packing, enhanced bonding, reduced cracking tendencies, workability, and durability collectively leads to the observed increase in strengths in concrete blended with coconut fibre ash and glass powder.
- The addition of coconut fibre ash and glass powder may slightly reduce the workability of the concrete mix.
- However, at 10% of glass powder and 20% of coconut fibre ash, the slump value is 78mm, which is satisfactory for use in normal concrete works.
- Concrete prepared by replacing 10% and 20% cement by coconut fibre ash and 20% glass powder addition gave satisfied results compared to ordinary concrete.
- Maximum values of compressive strength, tensile strength and flexural strength is obatined at 20% replacement of cement by coconut fibre ash and 10% addition of glass powder.

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