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Optimising Sawdust and Steel Fibre Ratios for Enhanced Compressive Strength in Sustainable Cement Composites

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Abstract

The construction industry's increasing commitment to environmental responsibility and the preservation of resources has accentuated the essential role of sustainable building materials. This study investigated the optimisation of sawdust and steel fibre ratios to enhance the compressive strength of sustainable cement composites. The experimental results indicate that the compressive strength consistently improved over a period of 28 days, irrespective of the quantities of steel fibres and sawdust added. The control beams achieved a compressive strength of 31.92 MPa. The study revealed that an increase in sawdust content led to a decrease in compressive strength, while higher proportions of steel fibres led to increased strength. The highest strength of 38.14 MPa was observed in the group with 1.0% steel fibre and no sawdust. These findings offer valuable insights into optimising sustainable concrete mixtures, emphasising the intricate balance between sawdust and steel fibres in enhancing compressive strength while promoting eco-friendly construction practices.

Keywords
Compressive Strength, Sawdust, Steel Fibres, Sustainable Cement Composites, Optimisation

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1. Introduction

The use of sustainable building materials has become increasingly vital in the construction industry due to the growing emphasis on environmental responsibility and resource conservation. One such area of exploration lies in the development of cement composites that leverage the unique properties of waste-derived sawdust and the reinforcing qualities of steel fibres. These materials have the potential to not only enhance the compressive strength of concrete but also promote eco-friendly construction practices. This paper embarks on an investigation into the optimisation of sawdust and steel fibre ratios in cement composites with the overarching goal of enhancing their compressive strength. By striking a balance between these two key components, the research aims to offer innovative insights into the development of sustainable construction materials, highlighting the critical interplay between environmentally-friendly additives and structural performance. This study contributes to the broader discourse on eco-conscious construction while addressing the need for stronger and more durable building materials.

The historical utilisation of sawdust in concrete modification extends far into the past, yet the exploration of its mechanical properties has been limited. Past investigations have revealed that sawdust, classified as organic waste, exhibits a heightened water absorption rate when juxtaposed with conventional concrete aggregates (Ali et al., 2023). This characteristic poses a challenge to the complete substitution of fine aggregates with sawdust. Nevertheless, empirical studies have demonstrated that partial replacement with sawdust imparts notable strength to the concrete matrix (Ubachukwu et al., 2023). Empirical data from these studies indicate that sawdust concrete achieves strength levels comparable to nominal concrete while exhibiting reduced density (Acharya, 2021).

This characteristic renders the composition suitable for fabricating non-load-bearing partition walls and floor slabs. Despite previous endeavours to employ sawdust concrete as lightweight concrete, no concerted efforts have been made to enhance its mechanical strength through the incorporation of steel fibres into sustainable cement composites.

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Earlier experiments underscore the adequacy of sawdust concrete strength within permissible limits, albeit experiencing a reduction compared to nominal mixes (Ruhal et al., 2016). Notwithstanding these findings, there is a notable absence of advancements aimed at augmenting the strength of sawdust concrete compositions in the extant body of literature.

Sawdust, comprising minute wooden particles sourced from diverse origins, constitutes an organic by-product resulting from timber processing, as reported by Tyagher *et al*. in 2011. Notably, the Nigerian sawmill industry generates a considerable volume of sawdust, estimated at approximately 5.2 million metric tons annually. This accumulation is particularly concentrated within the south-western region of Nigeria, as elucidated by Kehinde *et al*. in 2009. This geographic area, characterised by a tropical rain belt and the presence of extensive forest reserves, serves as the home to a significant number of sawmills, primarily in states such as Lagos, Oyo, Ogun, Osun, Ekiti and Ondo. The proliferation of these sawmills can be attributed to the surging demand for wood in the construction sector, as highlighted by Ohimain in 2012. The south-western region of Nigeria is known for its abundant forest resources, as reported by Okedere *et al*. in 2017, thereby fostering the establishment of numerous sawmills and the consequential accumulation of sawdust waste within this locale.

As per the findings outlined by Hamid and Behzad in 2011, concrete's intrinsic brittle characteristics necessitate the incorporation of a tensile reinforcement mechanism to enhance its tensile strength and strain capacity for suitability in structural applications. Conventionally, steel has been the preferred material for this purpose. In contrast to conventional reinforcing bars, which are strategically positioned in the concrete member's tensile zone, fibres, characterised by their slender, truncated form, are dispersed haphazardly throughout the concrete structure. These fibres, commercially obtainable and composed of materials such as steel, plastic, glass and natural elements, serve this reinforcement role. The data derived from the outcomes of this study is poised to contribute to the advancement of environmentally conscious practices, promoting ecological sustainability.

2. Methodology

Sawdust for this study was obtained from nearby sawmill facilities in the urban area of Ibadan. It was used as a partial substitute for fine aggregate, with weight replacements of 5% and 10% in the batching process. The steel fibres used were recycled from local steel binding wires found at various construction sites in the same area, and they were precisely cut to have a uniform length of 50mm. The primary cementitious material selected was Portland limestone cement (CEMII) with a density of 1440 kg/m³ and a strength class of 42.5, known for its versatility and suitability for various concrete mixes. The fine aggregate chosen was sharp sand from a local source, stored in a dry, shaded area to prevent moisture absorption. Coarse aggregate comprised granite with a maximum crushed size of 20 mm, meeting the study's concrete composition requirements.

To facilitate consistent blending with the concrete, sawdust underwent a thorough drying process for moisture removal. Subsequently, it underwent a screening procedure to eliminate any excessively large or small particles, ensuring uniformity in the mixture. The study's mix design relied on the empirical approach outlined by Sharma (2020), following the principles of the Design of Experiment (D.O.E). The concrete mix's ingredient quantities were meticulously determined in accordance with Sharma's procedures. A total of fifty-four concrete beams, each with dimensions of 100x100x400mm, were fabricated. These beams were organised into nine distinct groups, and the nomenclature of SC1 to SC9 was consistently employed. Furthermore, the weight proportions of the constituent materials for each concrete beam mixture are provided in Table 1.

In each concrete mix, the quantities of cement, coarse aggregate and water remained constant as did the water-cement ratio. The variation involved reducing the weights of fine aggregates by 5% and 10% through partial replacement with sawdust. Additionally, steel fibre materials were introduced at weights equivalent to 0.5% and 1.0% of the total concrete weight. The constituent materials were subjected to mechanical mixing within a portable concrete mixer to ensure uniform dispersion. During the casting process, a uniform layer-wise compaction approach was employed. After 24 hours of casting, the concrete beams were demolded and subsequently placed in curing tanks. Curing of the beams was conducted for durations of 7 and 28 days.

This procedure was followed by the compressive strength testing of the beams carried out with the aid of a compression testing machine known as universal testing machine (UTM). A total of twenty-seven specimens were subjected to testing, with three specimens selected from each of the categorical groups denoted as SC1 to SC9. The specimen weights were recorded prior to the commencement of the testing procedure.

Table 1: Weight proportions for 6 beams per mix

Materials	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9
Steel Fiber (%)	0	0	0	0.5	0.5	0.5	1.0	1.0	1.0
Sawdust (%)	0	5	10	0	5	10	0	5	10
Cement (kg)	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66
Fine Aggregate (kg)	18.93	17.98	17.04	18.93	17.98	17.04	18..93	17.98	17.04
Coarse Aggregate (kg)	26.76	26.76	26.76	26.76	26.76	26.76	26.76	26.76	26.76
Water-cement Ratio	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
Steel Fiber (kg)	0	0	0	1.02	1.02	1.02	2.04	2.04	2.04
Sawdust (kg)	0	0.95	1.89	0	0.95	1.89	0	0.95	1.89

3. Results and Discussion

Compressive Strength: The compressive strength of concrete beams was assessed at intervals of 7, 14, and 28 days of curing, with twenty-seven samples tested on each occasion. Table 2 illustrates the results of these compressive strength tests for concrete beams containing varying proportions of steel fibres and sawdust across different curing periods.

Overall, irrespective of the quantities of steel fibres and sawdust added, the compressive strength of the concrete consistently improved over time at 7, 14, and 28 days. For the control beams, which had no substitutes for steel fibres and sawdust, the average compressive strength after 28 days of curing was 31.92 MPa. Figure 4.1 reveals that as the sawdust content increased from 5% to 10%, the compressive strength of the beams gradually decreased. Specifically, the 28-day compressive strength of beams with 5% and 10% sawdust and no steel fibre decreased from 28.93 MPa to 22.48 MPa. Similar decreasing trends were observed at 7 and 14 days. Conversely, compressive strengths increased with higher proportions of steel fibre. For example, considering beams containing only 5% sawdust, an increase in steel fibre addition from 0.5% to 1% resulted in a rise in 28-day compressive strength from 30.03 MPa to 31.92 MPa.

The highest strength of 38.14 MPa was achieved in the group with 1.0% steel fibre and no sawdust, according to the 28-day compressive strength results. This group featured the maximum percentage of steel fibre addition, contributing to its increased strength. This pattern of strength results aligns with the findings of Tauseef *et al*. (2021) who suggested that 1% steel fibre by weight in concrete provides sufficient reinforcement to enhance strength more effectively than other percentages of steel fibre. Conversely, the group with 10% sawdust and no steel fibre exhibited the lowest compressive strength, measuring 22.48 MPa. The substantial addition of sawdust in this group significantly diminished the overall strength of the concrete

Table 2: Compressive strength test results

Materials	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9
Steel Fiber (%)	0	0	0	0.5	0.5	0.5	1	1	1
Sawdust (%)	0	5	10	0	5	10	0	5	10
Compressive Strength at 7 days (MPa)	22.23	18.38	15.64	25.15	19.52	16.49	25.26	20.57	18.50
Compressive Strength at 14 days (MPa)	28.31	26.25	20.25	31.00	27.88	22.21	34.98	28.83	25.28
Compressive Strength at 28 days (MPa)	31.92	28.93	22.48	34.91	30.03	25.24	38.14	31.92	28.53

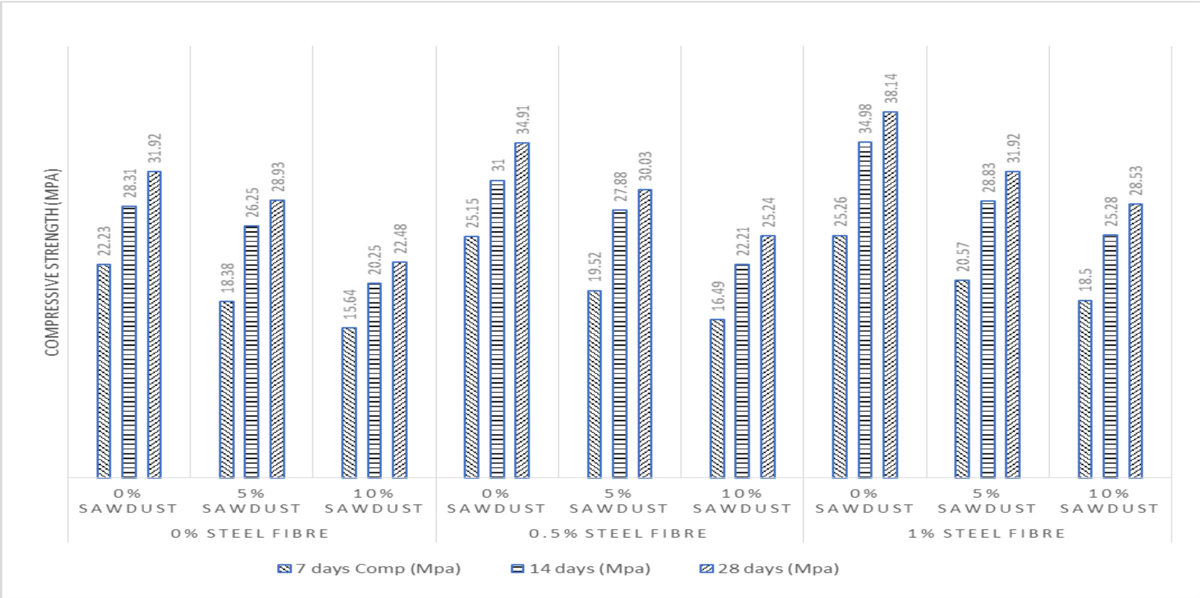

Fig 1: Summary of the compressive strength test results

4. Conclusion

The outcomes derived from the compressive strength assessment have unequivocally demonstrated a notable enhancement in the compressive strength of the concrete cubes' consequent to the incorporation of steel fibres. Notably, in the specific context of this study, the compressive strength exhibited a discernible decrement when fine aggregate was partially substituted with sawdust, exhibiting a contrasting trend in comparison to the scenario where fine aggregates are entirely supplanted by sawdust. Furthermore, it is pertinent to highlight that the integration of steel fibres together with sawdust yielded superior compressive strengths when compared with the utilisation of sawdust alone as replacement material

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