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Sawdust As A Sustainable Substitute: Experimental Insights On Lightweight Concrete For Non-Load-Bearing Members

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Abstract : Concrete is a composite material comprising 60-75 percent of aggregates, with 30-40% of this volume consisting of aggregates. Fine aggregate, a crucial component of concrete, often utilizes river sediment as the preferred option. The Indian furniture market is expected to achieve a CAGR of 10.9% during 2023-28, reaching $32.7 billion by 2026. The wood processing industry generates a substantial amount of sawdust. Besides its thermal combustion, this residue is abundantly available, looking for its consumable substitute in the industrial process. Natural river sand proves expensive in regions distant from the river source. Incorporating sawdust into the concrete industry could offer a solution for its safe disposal. A special type of concrete, known as Lightweight Concrete, is produced with a density lower than traditional concrete. This concrete is suitable for non-loading members, reducing the dead loads on structural members and consequently lowering design values for cost-effectiveness. In this experimental investigation, a normal M20 grade of concrete was prepared. Subsequent mixes were then prepared by replacing the sand fraction with sawdust. The resulting samples underwent testing for compressive strength, density, and water retention ability. The results obtained from the proposed mixed combinations suggest that utilizing sawdust for non-load-bearing members is feasible by producing lightweight concrete through the incorporation of sawdust.

Keywords — Compressive Strength, Density, Lightweight Concrete, Water Absorption, Workability.

I. Introduction

The concrete industry, constantly seeks innovative and sustainable solutions to enhance its environmental footprint. The incorporation of lightweight aggregates and innovative materials in concrete has garnered considerable attention in recent years. Sawdust, a byproduct of wood processing, emerges as a promising candidate due to its abundance and the challenges posed by the safe disposal of this material. This research delves into the utilization of sawdust as a substitute for sand in the production of lightweight concrete, offering a sustainable approach to waste management and resource utilization. The significance of lightweight concrete in non-loading members, where reduced dead loads lead to cost-effective structural designs. Li and Wang (2018) and Garcia et al. (2020) has highlighted the successful incorporation of waste materials, such as fly ash and slag, in concrete production. The substitution of traditional materials with waste byproducts has not only proven environmentally beneficial but has also shown improvements in certain mechanical and durability properties of concrete. These findings set the stage for considering sawdust as a potential waste material in concrete mixes. Ahmed et al. (2017) and Zhang et al. (2020) provides valuable insights into the mechanical properties, durability, and structural performance of lightweight concrete. These studies emphasize the need for innovative approaches to enhance these properties while maintaining or improving the sustainability of the material. Lightweight concrete's suitability for non-loading members and its potential cost-effectiveness in structural design are recurring themes in these investigations. The versatility of lightweight concrete in various applications is explored by researchers such as Lee et al. (2017) and Patel et al. (2020). Lightweight concrete finds its niche in non-loading members, providing structural designers with opportunities to optimize material usage and reduce dead loads. Applications in precast elements, high-rise buildings, and thermal insulation demonstrate the broad scope of lightweight concrete in diverse construction scenarios. The field of lightweight concrete has seen significant advancements, as demonstrated by studies conducted by Khan et al. (2018) and Wang and Li (2020). Ahmed and Soroushian (2019) and Kim et al. (2022) emphasize the importance of selecting appropriate lightweight aggregates in the design of lightweight concrete. Cost-effectiveness and feasibility, were explored by Zhao et al. (2019) and Gupta et al. (2022). These studies provide insights into the economic viability of lightweight concrete solutions, considering factors such as material availability, construction efficiency, and long-term durability. Such considerations are essential for industry professionals and decision-makers in choosing suitable construction materials. In the quest for more sustainable and efficient construction practices, the literature reveals diverse benefits of lightweight concrete, ranging from its capacity to reduce structural dead loads to its enhanced thermal insulation properties and contributions to environmental sustainability. Jones et al. (2018) and Smithson (2020) emphasize the fundamental advantage of lightweight concrete in reducing structural dead loads. The lower density of lightweight concrete compared to traditional concrete results in decreased overall weight in construction projects. This reduction in dead loads is particularly advantageous in non-load-bearing elements, contributing to more cost-effective structural designs. Zhang and Liu (2019) and Gupta et al. (2021) investigated the role of lightweight aggregates such as expanded clay or perlite contribute to the material's ability to resist heat transfer. Thus making lightweight concrete a favorable choice for applications where thermal insulation is a critical consideration, such as in building envelopes and energy-efficient constructions. Wang et al. (2017) and Patel and Sharma (2020) have highlighted the improved fire resistance properties of lightweight concrete. The presence of lightweight aggregates results in a lower thermal conductivity, leading to better performance under high-temperature conditions. This aspect makes lightweight concrete a preferred material in fire-prone regions and for structures requiring enhanced fire safety. Tan et al. (2018) and Li et al. (2020) underscores the practical advantages of lightweight concrete in terms of ease of handling during construction. The reduced weight facilitates easier transportation, placement, and manipulation of concrete elements. This feature is particularly valuable in precast concrete applications, where efficiency in manufacturing and installation is crucial. Kim and Lee (2019) and Chen et al. (2022) have examined the mechanical properties and durability of lightweight concrete. While there may be a slight trade-off in compressive strength compared to traditional concrete, the research suggests that lightweight concrete can meet the required structural standards for many applications. Additionally, durability studies show that lightweight concrete can exhibit favorable long-term performance. The environmental benefits of lightweight concrete have been explored in research by Xie et al. (2018) and Nisar et al. (2021). The use of alternative lightweight aggregates, such as recycled materials or industrial byproducts, contributes to sustainable construction practices. This aligns with the broader goal of reducing the environmental impact of construction activities by utilizing materials that are both lightweight and eco-friendly. The extensive literature review underscores the manifold advantages of lightweight concrete, encompassing reduced structural dead loads, improved thermal insulation, enhanced fire resistance, ease of handling during construction, favorable structural and durability properties, and notable cost-effectiveness in design. Building upon these well-established foundations, this research endeavors to push the boundaries further by exploring the viability of utilizing sawdust as a substitute for traditional fine aggregates in the manufacturing of lightweight concrete. By integrating the knowledge gleaned from prior studies, this investigation aims to contribute to the evolving discourse on sustainable construction practices, offering a technically sound and environmentally conscious approach to concrete production.

II. MATERIAL

A. Cement

Ordinary Portland Cement (OPC) of 43 Grade served as the primary binder material in the formulation of the concrete. The choice of this particular cement grade aligns with industry standards and specifications, ensuring the desired performance and reliability in the ensuing concrete manufacturing process.

B. Fine Aggregate – Natural River Sand

The fine aggregate employed in the concrete manufacturing process was sourced from Sindh River, Natural Sand was extracted from the mid-course of this river flowing through the Ganderbal district JK(UT). The sand procurement adhered to stringent quality standards, ensuring its purity and absence of impurities or debris. Experimental verification established that the sand conformed to Zone III specifications, meeting the requisite criteria for particle size distribution and other geotechnical properties mandated for optimal concrete performance.

Figure 1 – Raw Material used for the different concrete mix.

C. Coarse Aggregate

The coarse aggregate utilized in the concrete production process comprised Crushed River Boulders obtained from the crusher zone situated in Ganderbal district. Rigorous quality control measures ensured that the aggregates were devoid of impurities and clay coatings. Experimental verification confirmed the adherence of the aggregates to a nominal size of 20 mm, aligning with specified standards for particle size distribution and contributing to the desired mechanical properties and structural integrity of the resultant concrete mixture.

D. Water

Ordinary tap water, sourced through municipal channels, served as the water component for the concrete mix. Experimental verification of the pH level yielded a measured value of 7.1, indicating a neutral pH environment. The container designated for water storage underwent scrutiny to ensure its free from oil residues and other impurities, maintaining the quality and purity of the water used in the concrete preparation process.

E. Saw Dust

Sawdust, a byproduct originating from woodworking operations such as sanding, milling, routing, and sawing, comprises minuscule wood chips generated during these processes. This dry wood material is characterized by its composition, containing cellulose, hemicelluloses, lignin, and approximately 5-10% other materials. In our experimental endeavors, the sourced sawdust was obtained from a band saw mill in close proximity. The specific fraction of sawdust selected for utilization was derived during the sawing process of timber from the Poplar (Populus deltoides) tree species. Prior to its integration into the concrete mixture, the sawdust fraction underwent a meticulous preparation step, being sieved through a 4.75 mm sieve to ensure a consistent and defined particle size distribution.

III MIX PROPORTION & SAMPLING

The concrete mix for M20 grade was meticulously formulated with a mix ratio of 1:1.5:3, establishing a reference mix proportion. The water-cement ratio was consistently maintained at 0.45 to ensure uniformity across all mixes. Subsequent variations were introduced by successively replacing sand fractions with increments of 5%, 10%, 15%, 20%, and 25% in relation to the reference mix. The tabulated data (Table I) below comprehensively represents the corresponding fractions of materials employed in the preparation of the various mix proportions. This systematic variation in the mix proportions facilitated a comprehensive investigation into the influence of sawdust substitution on the performance characteristics of the concrete.

Table I : Various Mix Proportion (for 1 cubic meter)

Mix	Cement (kg)	Sand (kg)	Saw Dust (kg)	Coarse Aggregate (kg)	Water (kg)
Reference Mix	400	600	-	1200	180
Mix 1 (5% Sawdust)	400	380	20	1200	180
Mix 2 (10% Sawdust)	400	360	40	1200	180
Mix 3 (15% Sawdust)	400	340	60	1200	180
Mix 4 (20% Sawdust)	400	320	80	1200	180
Mix 5 (25% Sawdust)	400	300	100	1200	180

The concrete manufacturing process commenced with the dry mixing of ingredients in the concrete mixer for a duration of 2-3 minutes. Subsequently, the predetermined water quantity was added, and thorough mixing ensued for an additional 5-7 minutes to achieve a homogenous consistency. A fraction of the prepared concrete was set aside for an initial workability assessment, while the remainder was promptly poured into cube molds to form samples. The cube molds were allowed to set for 24 hours in shaded conditions before being demolded. Following demolding, the concrete specimens were transferred to a water curing tank for a stipulated duration of 28 days to facilitate optimal hydration and strength development. Upon completion of the curing period, the samples were carefully removed from the water curing tank, subjected to a thorough cleaning process, and subsequently air-dried in preparation for further experimental investigations. This meticulous procedure ensured the controlled and standardized preparation of concrete samples, paving the way for a comprehensive analysis of the effects of sawdust substitution on the mechanical and durability properties of the concrete.

Figure 2 – Sample being prepared for conducting investigation for different concrete mix.

III. EXPERIMENTAL ANALYSIS & RESULTS

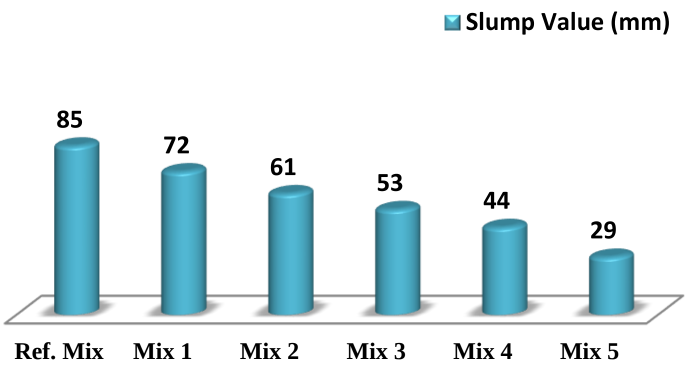
A. Workability

Slump test was performed for investigation of slump values. The slump test was carried in accordance with B.S:1882 PART2:1970. The slump cone mould was filled successively in 5 layers, each being tamped 25 times with the tamping rod. After sometime the mould was removed and the concrete specimen is exposed without the lateral mould cover, resulting deformation in its height. The difference in the height with respect to the height of the mould and that of height point of the specimen being tested is referred as the slump value of the concrete mix.

Figure 3 – Slump Test being performed for the concrete mix.

The fraction of freshly prepared concrete for each mix was checked for the workability. The test results obtained for different concrete mix have been illustrated in the Figure-4 below.

Figure 4 – Variation of Slump Values with respect to different Concrete mix.



Workability of different concrete mix showed a decreasing trend with the increase in the saw dust fraction, reflecting the impact of sawdust as a partial replacement for traditional aggregates in the mix. As the sawdust fraction increases from 0% in the reference mix to 25% in Mix 5, there is a noticeable decline in slump values. This reduction in slump suggests that the addition of sawdust is contributing to a decrease in the workability and flowability of the fresh concrete. Sawdust, being a lightweight and absorbent material, tends to absorb water, leading to a higher demand for water in the mix and resulting in reduced workability. The reference mix, with no sawdust, exhibits the highest slump value, indicating greater ease of placement and compaction. Saw dust being absorbent in nature leads to the sequestration of water from the mixture, diminishing the available water for lubrication and flow. Additionally, the irregular and lightweight nature of sawdust particles hinders the workability of the mix by disrupting the inter-particle lubrication, resulting in a stiffer consistency.

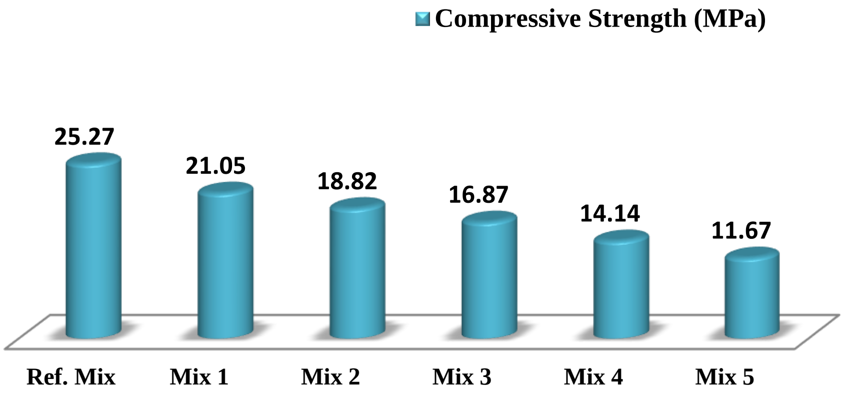
B. Compressive Strength

The investigation of compressive strength for each concrete mix was conducted through the performance of cube tests, adhering to the guidelines outlined in the Bureau of Indian Standards (BIS) specification 516:1959. Cube specimens representative of each mix were subjected to compressive loading using a universal

Figure 5 – Compressive Test being performed for the concrete mix.

testing machine, with a loading rate of 4.5 kN per second. The compressive strength of the concrete mixtures was determined by dividing the average failure load obtained from three cube specimens by the corresponding cross-sectional area of the cubes. This method aligns with established standards and ensures a comprehensive assessment of the concrete's compressive strength characteristics. The utilization of three cube specimens and the calculation of an average value enhance the reliability and representativeness of the obtained compressive strength data for each concrete mix. After 28 days of curing, concrete cubes are dried and tested for compressive strength. The results obtained for different concrete mix containing different saw dust fraction has been illustrated in Figure-6 below.

Figure 6 – Compressive Strength obtained at 28 days of age, with respect to different Concrete mix.

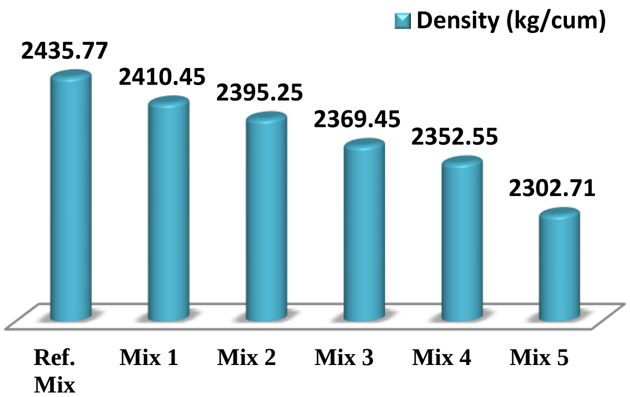


This experimental study highlights the impact of sawdust content on the compressive strength of concrete after 28 days. As the sawdust content increases, there is a consistent reduction in compressive strength. As evident from the results, the compressive strength of concrete decreases with an increase in the percentage of sawdust. This reduction can be attributed to the lower strength and irregular shape of sawdust particles compared to conventional fine aggregate. The presence of sawdust introduces voids and weakens the interlocking structure of the concrete matrix, resulting in a decline in compressive strength. Also as observed in the workability check, sawdust tends to retain the water decreasing the water-cement ratio in the concrete mixture, affecting the hydration process of cement and ultimately impacting the strength development.

C. Density

The assessment of concrete density is a crucial aspect, the technical procedure involves considering average weight of three cube specimens for each mix after subjecting them to a meticulous 24-hour oven-drying process, undergo drying phase to eliminate any residual moisture. Following the drying process, the cubes are weighed using a calibrated scale, and their dimensions are measured with calipers. The average weight and volume of the cubes are then utilized to calculate the concrete density. This method ensures accurate and consistent density measurements, contributing to the reliability and durability of the concrete structures in various construction applications. This investigation was also carried after the 28 days of curing. Figure 7, depicts the variation of density in various concrete mix.

Figure 7 – Density with respect to different Concrete mix.

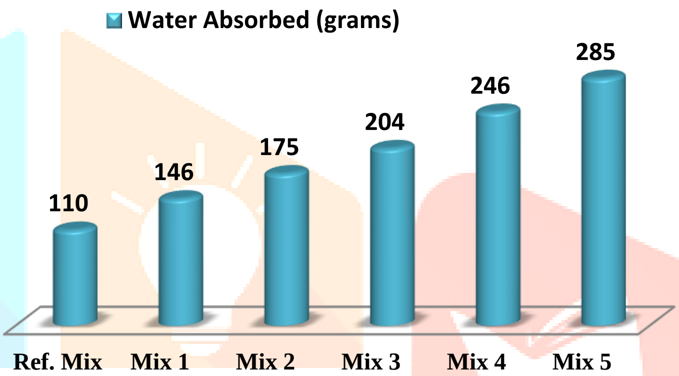


The results reveal a consistent trend of decreasing density with an increasing proportion of sawdust. The lower density is attributed to the lightweight nature of sawdust compared to traditional aggregates. Sawdust is a lightweight material with a lower specific gravity than conventional sand, which results in a reduction in the overall density of the concrete mixture as the proportion of sawdust increases. This lower density is a consequence of the void spaces created by the relatively larger volume of sawdust particles, leading to a less compact and lighter composite.

D. Water Retention

The assessment of water absorption in concrete plays a pivotal role in determining its durability. The procedure involves initially drying representative concrete specimens in an oven until a constant mass is achieved, followed by weighing to determine the dry mass. Subsequently, the specimens are immersed in water for a specified duration – 24 hours, after which they are quickly dried, and their saturated mass is measured. The water absorption is then calculated as a percentage based on the difference between the saturated and dry masses. This parameter serves as a key indicator of concrete porosity, with lower water absorption percentages generally associated with reduced porosity and enhanced durability. Figure – 8, depicted the water retention ability for various concrete mix.

Figure 8 – Water Absorbed by different Concrete mix.



The results illustrates, that the water absorption capacity of sawdust modified concrete at different replacement levels. The data shows the relationship between the amount of saw dust substituted to sand and the corresponding amount of water absorbed in grams. As the moisture content increases from 0% to 25%, there is a noticeable upward trend in the water absorbed by the sawdust. At 0% sawdust content – reference concrete, the sawdust absorbs 110 grams of water. As the sawdust replacement level is increases in increments of 5%, the water absorption also increases, reaching 285 grams at 25% saw dust replacement level. The variation pattern suggests a positive correlation between the moisture content and the water absorption capacity of sawdust induced concrete.

IV. FUTURE WORK

The development of lightweight concrete incorporating sawdust as a partial replacement for traditional aggregates presents a promising avenue for future research and applications. Empirical findings on workability, compressive strength, density, and water retention provide valuable insights for optimizing mix proportions and achieving an optimal balance between reduced density, improved strength, and enhanced workability. Future studies should focus on assessing the long-term durability of this material, considering environmental factors and exploring innovative applications such as precast components or insulating materials. Additionally, efforts can be directed towards enhancing mechanical properties through the incorporation of reinforcing materials. Comprehensive life cycle analyses are crucial for understanding the environmental impact of lightweight concrete with sawdust, including energy consumption, carbon footprint, and resource utilization. As this material gains traction, the development of standardized guidelines and codes specific to its production and application is necessary. Economic feasibility studies should also be conducted to evaluate the cost-effectiveness of large-scale implementation compared to traditional concrete. In sum, addressing these aspects will contribute to advancing the knowledge and practical implementation of lightweight concrete with sawdust, offering sustainable and innovative solutions in the construction industry.

V. CONCLUSION

- The inclusion of sawdust in concrete mixtures impacts both fresh and hardened properties.
- Sawdust fraction inversely affects workability, evident from the decreasing trend in slump values with increasing sawdust content. Higher sawdust fractions lead to reduced workability due to the absorbent nature of sawdust, which diminishes available water for lubrication and disrupts inter-particle lubrication.
- Compressive strength decreases consistently as the sawdust content increases in concrete mixes. Lower strength and irregular shape of sawdust particles introduce voids and weaken the interlocking structure of the concrete matrix, impacting compressive strength. In addition to this, the water retention by sawdust affects the water-cement ratio, influencing the hydration process and ultimately decreasing strength.
- Density of the concrete mix decreases as the proportion of sawdust increases. The lightweight nature of sawdust, with lower specific gravity compared to traditional aggregates, contributes to the overall reduction in concrete density. Void spaces created by larger sawdust particles result in a less compact and lighter composite.
- Water absorption capacity of sawdust-modified concrete increases with higher sawdust replacement levels. Positive correlation observed between sawdust content and water absorption capacity, showcasing the absorbent nature of sawdust. The results emphasize the importance of considering water absorption in concrete, with potential implications for porosity and durability.
- These empirical findings offer valuable insights for the optimization and application of lightweight concrete formulations wherein sawdust serves as a partial substitute for conventional aggregates.

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