Review Paper

Utilization of sawdust composites in construction—a review

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Abstract

This study presents the use of sawdust ash as a substitute in the production of sustainable building materials. Inappropriate dispose of wood-waste causes serious environmental problems as it results in atmospheric degradation, emissions of greenhouse gases and the destruction of aquatic and organic products. This review article combines research results from past studies into the usage of sawdust as an alternative for essential elements in construction composites. The result of this study shows that structural concrete can be manufactured with compressive strengths more than 20 MPa by replacing moderately 5–17% of the sand with sawdust or 5–15% of the cement with sawdust ash. By partially substituting sawdust that ranges between 10 and 30% of sand used in the production of blocks and bricks, sawdust blocks and bricks having compressive strengths greater than 3 MPa can be created. According to the findings of this study, sawdust has the potential to make construction composites that are strong, absorb water, and have an elastic modulus that meet international standards. The study concludes that sawdust composites are intriguing due to having hushed heat conductivity, a prominent sound absorption, as well as efficient sound wadding. From the findings, it is demonstrated that an increase in the utilization of sawdust for construction purposes will reduce the possibility of sawdust as a pollution to the environment, and will also ease the costs of disposal.

Article Highlight: Key findings and implications of the paper

- Utilization of sawdust composite in construction is relevant because it can serve as a sustainable material; Sawdust been a byproduct of the timber industry is often considered waste. However, by utilizing sawdust in composite materials, it provides a sustainable alternative to traditional building materials such as concrete or steel. Also, it helps improve insulation because sawdust composites have excellent insulation properties due to their low thermal conductivity, making them ideal for use in walls, floors, and roofs. Additionally, it helps reduce cost of construction because composites of sawdust are typically less expensive than traditional building materials, thus making them an attractive option for cost-conscious builders.
- Sawdust composites are lightweight and easy to handle, thus making them ideal for use in structures where weight is a concern. Also, it helps improved durability; Sawdust is highly durable and resistant to decay, making them a long-lasting alternative to traditional building materials. By utilizing sawdust in construction, the carbon footprint of the construction process can also be reduced. This is because sawdust composites require less energy to produce and have a lower carbon footprint than traditional building materials. Also, in terms of design flexibility, Sawdust composite can be molded into a variety of shapes and sizes, making it a versatile material for construction. This allows for greater design flexibility and the creation of unique building designs.

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- The use of sawdust composite in construction can improve the health and safety of workers and occupants of the building because sawdust composite does not produce the same level of harmful dust and chemicals as traditional building materials, which can be harmful to human health. Overall, the utilization of sawdust composite in construction has numerous positive implications, which includes, providing an environmentally friendly, cost-effective, and durable solution for building construction, improved energy efficiency, greater design flexibility, and improved health and safety.

Keywords Concrete · Compressive strength · Heat conductivity · Sawdust with sawdust composites

1 Introduction

It is impossible to overstate the importance of having access to economical building materials in order to provide appropriate housing for the growing global population, particularly in developing nations. The necessity to find local resources as alternatives for the construction of useful but affordable houses in both rural and urban regions is growing as costs rise significantly [1]. Price of building materials has been recognized as one of the obstacles to effective housing delivery [2]. A decrease in the cost of materials would undoubtedly result in significant savings in the entire cost of building production because it made up two-thirds of the cost [3]. Cement in particular is responsible for about 42% of cost of building and the demand has proliferated dramatically by current construction boom [4–6]. Cement is produced in surplus amounts globally due to its extensive use in concrete. Every year, more than 5 billion tons of cement are produced globally [7, 8]. For every 600 kg of cement produced, around 400 kg of carbon dioxide (CO_2) gas is released [9] which is harmful to the environment. It is anticipated that partial cement replacement will be used to meet the growing demand for cement, hence the need to research on industrial and agricultural waste as alternatives for replacing cement. The potential for using industrial and agricultural waste as cementitious materials was discovered during the quest for substitutes for cement or alternative binders. If these fillers possess pozzolanic qualities, the resulting concrete gains technical advantages and can replace more cement in a given amount [10]. A form of industrial and agricultural waste having these potential is sawdust. Sawdust is a well-known agriculture and by-product waste material resulting from the wood industry [11]. It is generated as a waste material when timbers are mechanically milled into different sizes and shapes. Many environmental problems are caused by sawdust wastes, wherein the scarcity of space for land fill is a major concern and a severe threat to developed nations. The excessive sawdust wastes that are accumulated due to the activities of factories, mills, and houses are ever growing annually. It is estimated that the annual generation of wood waste in the United States of America, Germany, the United Kingdom, and Australia is around 64, 8.8, 4.6, and 4.5 million tonnes per years, respectively, and more than 40% of these amounts are not recycled [12–14]. The high percentage of non-recycled wood wastes shows the deficiency of sufficient recycling procedures and strategies.

The best way to deal with issues related to wood waste is to use wood fuel to produce energy. Although thermal combustion typically results in reduction of the size of wood waste, it produces another issue which is wood ash (Sawdust ash). About 3 million oodles of wood ash are generated annually in the USA alone [15]. The majority of the time, the timber industry has its own tiny boiler units that burn created wood waste as fuel to produce heat energy for added processes, such drying the final products. Thus, it is vital to recycle wood wastes on a daily basis and utilize them effectively in cement-based composites/concretes to guarantee their harmless discarding as an environmental remedy. As cement is the steepest component of concrete, using ash gotten from sawdust as a replacement for cement is anticipated to offers a number of benefits, including reduced pollution, perfect waste utilization, and also result in a significant reduction in construction costs over the long term [16–18].

In subsequent section of this review, the use of sawdust composite for construction purpose with emphasis on its availability and how it is usually discarded was discussed. This is followed by the methodological section which presents the detailed procedure involved in the source of relevant scholarly literature works reviewed. In Sect. 4, different characteristics of sawdust was discussed with emphasis on its engineering properties. Section 5 presents the benefits and relevance of utilizing sawdust in construction. The next section involves the challenges and future trend. The succeeding section further presents the identified research gaps from the reviewed literature and finally in the last section, the conclusion is drawn from the investigative study.

2 Sawdust composite for construction purpose

2.1 Sawdust

The lignocellulosic waste product of sawing, planning, cutting, drilling, polishing, making furniture, and riveting is called sawdust. This waste stream is composed of tiny wood particles or small, uneven wood chips [19, 20].

The waste product from lumber sawmills is sawdust. The waste powder that is extracted from timbers for a specific purpose is known as saw dust. Tropical nations are a great source of sawdust. Only sometimes is this sawdust utilized as fuel [21]. Sawdust has been used in construction for a number of years now. These materials are lightweight and portable. Sawdust has different physical and chemical characteristics that vary from one tree to another. Saw dust is the waste powder that is selected from timbers that have been sawed for a specific purpose [21]. Sawdust ash is the waste product that emerges from sawing and milling wood, which produces sawdust. Sawmills can be found in practically every town in a country, and sawing is a continual daily activity that produces a lot of garbage. Sawdust is routinely dumped, burned, or landfilled in an open area. [22, 23]. Sawdust is a strain to disposal sites and contributes to greenhouse gas emissions when burned [24]. The most practical option for saw millers to get rid of sawdust is by open fire, In spite of the smog and associated risks to public health [25, 26]. When sawdust is thrown into streams and rivers, it can do substantial damage to aquatic life because wind and rain can carry it into the surface water. Carelessly spreading sawdust on land also kills vegetation and puts wood dust into the atmosphere [27]. Additionally, utilizing wood-based building materials such as sawdust blends reduces the consequences of climate change [28, 29]. Significant amounts of carbon energy may perhaps be hoarded through the use of sawdust blends in place of metals, concrete, and other anticyclone energy crafted products [29, 30]. This review study was inspired by the numerous opportunities for using sawdust, as a raw material to create construction composites that exceed transnational requirements. This prospective application has not yet been thoroughly investigated, especially in underdeveloped nations where the uncontrolled dumping of sawdust is common. It is hoped that this evaluation of the literature would spur additional study into sawdust composites and encourage greater use of these composites in building. This would lessen the threat of sawdust environmental pollution and advance the development of green construction materials.

2.2 Availability, usage and dumping of sawdust

2.2.1 Availability of sawdust

The sawmilling process is a substantial supplier of sawdust. The measure of sawdust engendered by sawmilling is swayed by the productivity of the sawmill, which may be gauged by rivaling the mass and attribute of convalesced sawn board with the ensuing wastes generated [31]. The quantity of sawdust created varies depending on the technology employed. An investigation by Kambugu et al. [32], inadequate equipment for timber sawing causes a significant amount of sawdust to be produced during the timber ripping process.

Table 1 below lists the annual production quantities of sawdust in a few key global locations, together with the extent of wood waste and sawdust produced by sawmills. If this is merely thrown out as waste, it implies a significant environmental concern.

2.2.2 Several usage and discarding of sawdust

Sawdust is frequently used for mulching, composting, and bedding for cattle and poultry outside of construction [39]. Before refrigeration was invented, sawdust has been utilized to preserve ice frozen in icehouses during summertime. It creates a slower-melting and more robust kind of ice when combined with water and frozen. It can occasionally be used to soak up spilled liquids, making it easier to gather or clean up the mess [19]. Sawdust is regarded as a top-notch raw material for making biomass briquettes and wood pellets, both of which are utilized as solid fuels [40, 41]. The majority of this sawdust is typically discarded through open dumping, open burning, and occasionally landfilling. Figure 1 depicts the common practice of indiscriminate burning and discarding sawdust in most developing countries.

2.3 Sawdust as other materials used in construction

Composite materials made of sawdust have long been used in building. For example, it has been applied for more than 40 years to produce sawdust concrete [19]. Other sawdust composites used in the building sector, according to literature, outside concrete include its use in particleboard, its use in floor slabs, partitioning, paneling, attic, cast - in - situ, concrete blocks, and bricks.

2.3.1 Use in particleboards with associated artefacts

Particleboard is made with a substantial measure of sawdust and wood shavings in the United States [42]. Between 2000 and 2017, the manufacturing of timber products like plywood, laminated particle sheets, as well as particleboard increased globally by 125%. The Asia-Pacific regions produced the majority of these goods (62%), with Europe (21%), Latin America (11%), the Caribbean (5%) and Africa (1%), between 2012 and 2016 [43, 44].

Particleboards and associated goods like plywood and sawn wood are in constant demand in Zambia. According to projections, demand for these items will rise by 39%, from 501,100 m^3 in 2010 to 698,700 m^3 in 2025 [45].

Particleboards and similar lumber like low-density fiberboard are made by blending various ratios of wood shavings, sawmill flakes, or sawdust with a synthetic mastic faux or another appropriate binder [28, 46]. For instance, the characteristics of fiberboard manufactured from sawdust and phthalate resin using styrene as a binding material met the standards of American National Standard Institute (ANSI) A208.1, according to Abdulkareem et al. [46]. Urea formaldehyde (UF) particleboards were studied and it was found that they were not so resilient, hard, and more suitable for use in most conditions [46]. According to a report by Dotun et al. [47], sawdust particleboards made from a mixture of discarded polyethylene terephthalate fictile and sawdust are best used inside. However, the investigation also revealed that there were just a few structural and load-bearing uses for these goods. Similar suggestions were made by Akinyemi et al. [48], who stated that panels created from composites of sawdust and corncob that were bound with urea formaldehyde were only suited for indoor purposes in buildings and not ones that were intended to support loads. Erakhrumen et al. [49] show that a high cement concentration enhances particleboard qualities such as sturdiness, strength properties, and specific gravity for combinations of sawdust from Pinus caribaea M. with coconut husk or coir (Cocos nucifera L.). However, these characteristics diminished as the amount of coir in the combination rose. It is well known that sawdust composites with expanded polystyrene glued between them have excellent heat conductivity properties. These goods are accepted for use in suspended ceilings and room partitioning [50]. For cladding and walling, sawdust and cement composites can be employed. However, it's vital to pick wood carefully for this application that has cement-compatible components. [51].

2.3.2 Floor panes

Floor panels are prefabricated elements that are used to create a floor surface. They are available in a wide variety of materials, sizes, and shapes, including concrete, ceramic, stone, wood, and more [52]. These panels or tiles are typically manufactured offsite and then installed on the building site, making construction more efficient and reducing waste. Floor panels or tiles can offer several advantages over traditional flooring materials, including faster installation, easier maintenance, and greater design flexibility. They can also be used in combination with underfloor heating systems to provide greater comfort and energy efficiency.

In a report of Chanhoun et al. [53], composites were made from wood waste, polystyrene waste, and plastic waste. These composite materials could be utilized for formwork sandwich boards, ceilings, door cores, and self-adhesive panes or boards in addition to interior and external flooring. An inventive concrete sandwich panel that was studied in Iraq consisted of two outer stratums of

Table 1 Estimated measures of sawdust spawned annually from sawmills

Proportion of wood waste spawned from total sawmilling input volume (%)	Proportion of sawdust produced (%)	Amount of sawdust engendered per annum (million m^3)	Country	References
31–56	16–35	8.6^+	Nigeria	[31]
44	10	–	Nigeria	[33]
48	20	4.7^+	South Africa	[34]
27.5	14.7	–	Ghana	[23]
–	35	9.5^+	Mexico	[35]
		3.0^+	Uganda	[36]
		2.72	Chile	[37]
		2.8	Austria	[38] $^{++}$
		4.8	Germany	[38] $^{++}$
		3.4	Finland	[38] $^{++}$
		0.54	Latvia	[38] $^{++}$
		5.3	Sweden	[38] $^{++}$

–No obtainable info; $^+$Quantity gaged from volumes using an approximate sawdust density of 210 kg/m^3, $^{++}$An average from four years sawdust output data.

reinforced concrete sandwiching a stratum of light weight concrete (LWC). Truss reinforcement acting as shear connectors was used to join these components together. In the inner wythe, sawdust was utilized as aggregate in sandwich slab panels, which had higher strength than panels made of polystyrene (styropor) or porcilenite. [54]. It was discovered by Chung et al. [55] that a sand-sawdust stratum can reduce vibrations in lightweight wooden floor or ceiling systems. The experiment's wooden floor had a ceiling, a sound-absorbing hollow gap stuffed with fiber infill, and a high floor built of a sand-sawdust mixture. Theoretical predictions and experimental findings show that the silt layer dampened vibrations between 10 and 200 Hz.

2.3.3 Lightweight sawdust concrete

Concrete used for structural lightweight construction contains densities between 1120 and 1920 kg/m3 with minimal strength of 17 MPa [56, 57]. Wood waste such as sawdust, is a viable replacement element for the development of aerated concrete and energy absorption construction hybrids since it has minimal density and good thermal wadding value [42]. Ahmed et al. [58] claimed that a concrete mix of coarse aggregate, sand, and cement with various measures of sawdust as a fractional surrogate for sand could be used to create standard and lightweight concretes that were both ecologically friendly and thermally efficient.

2.4 Economic advantages of Sawdust

Sawdust, a by-product of wood processing, can be used as a sustainable construction material with several economic advantages;

2.4.1 Low cost

Sawdust is abundant and readily available, which makes it an affordable construction material. The cost of sawdust can be significantly lower than traditional building materials such as cement, bricks, and steel.

(a) Sawdust burning close to a residential area; (b) Sawdust burning at a sawmill;

(c) Sawdust burning at a sawmill; (d) Ditching of sawdust along a stream's banks

Fig. 1 Ditching of sawdust in the open [5]

2.4.2 Energy efficiency

Sawdust is an excellent insulator and can be used as a thermal barrier, reducing the need for heating and cooling systems. This can help to lower energy bills and reduce the carbon footprint of a building.

2.4.3 Lightweight

Sawdust-based materials are lightweight, which makes them easy to handle and transport. This can reduce construction costs and make building processes faster and more efficient.

2.4.4 Easy to work with

Sawdust-based materials can be easily shaped and molded into different forms, allowing for more flexibility in design and construction.

2.4.5 Low carbon footprint

Sawdust-based materials have a lower carbon footprint than traditional building materials, as they are made from renewable resources and require less energy to produce.

2.4.6 Biodegradable

Sawdust-based materials are biodegradable and can be easily disposed of without harming the environment. This reduces waste and promotes sustainability.

Overall, using sawdust as a sustainable construction material can offer several economic advantages, including lower costs, energy efficiency, ease of use, and environmental sustainability.

2.5 Durability and stability of sawdust composite in construction

Sawdust composites are materials made by combining sawdust with a binder material, such as resin, to create a strong and durable building material. The durability and stability of sawdust composites depend on the type of binder material used, the quality of the sawdust, and the manufacturing process used to create the composite [59]. Sawdust can be utilized in concrete to produce lightweight concrete and this type of concrete is known as sawdust concrete made by mixing sawdust with cement and water. Its durability and stability depend on a variety of factors, including the quality of the sawdust used, the proportions of sawdust, cement, and water in the mixture, and the curing conditions.

In the study of Hisham et al. 2020 [60], it was established that sawdust concrete can be a durable and stable material when made properly. The addition of sawdust to the mixture can improve the thermal and acoustic insulation properties of the concrete, making it a popular choice for construction in cold climates. However, it is important to note that sawdust concrete may be more susceptible to water damage than traditional concrete due to the organic material present in the sawdust. Proper curing is particularly important for sawdust concrete, as it allows the mixture to fully set and harden, improving its strength and resistance to damage.

In general, sawdust composites can be a durable and stable material for use in construction projects. The addition of sawdust to the composite can improve its strength and reduce its weight, making it a popular choice for applications such as flooring, furniture, and structural panels.

The durability and stability of sawdust composites can be further improved by using high-quality sawdust that is free of contaminants and by carefully controlling the manufacturing process [60]. This may include using specific ratios of sawdust to binder material, applying heat or pressure during the manufacturing process, and ensuring proper curing or drying times.

Overall, sawdust composites can be a sustainable and cost-effective building material that offers good durability and stability when used appropriately and made with care.

3 Methodology

In order to provide a sustainable construction material, this detailed review concentrates on evaluating the prospects of using industrial waste derivatives, mainly sawdust, as a sustainable alternative to traditional building materials. To achieve this, a thorough analysis of pertinent and related published literature obtained from scholarly research database and indexing systems including PubMed, Science Direct, Scopus, and Web of Science was done. The extracted articles' abstracts and titles were evaluated for eligibility and retrieval criteria. Furthermore, screening exercises and selection of relevant articles was done. After the initial search, the articles were screened based on their relevance to the research topic and inclusion criteria. The inclusion criteria include factors such as the form of sawdust composite, the construction application, and the study design. The selected articles were then critically appraised for their quality and relevance. The information from the literature works was skillfully structured into categories to evaluate the utilization of sawdust composite in construction, such as properties and characteristics of the sawdust composite, the construction application the results of the study, Additionally, gaps in the literature were identified, and recommendations for future research was made as shown in the methodology flowchart in Fig. 2.

4 Different characteristics of sawdust and sawdust ash

4.1 Physical and chemical characteristics of SDA

Physical attributes refer to the fundamental characteristics of wood and how it reacts to external forces; examples include structure and texture, density, moisture, specific stiffness, thermodynamic properties, etc. [14]. It is essential to comprehend physical properties as they have a significant influence on how effectively a material performs and how strong it is when used in structural applications.

Elinwa & Mahmood's findings [62] indicate that SDA complies with the requirements as per specifications as depicted in Fig. 3 above. Additionally, when the percentage of SDA rises, the concrete's workability also declines. Additionally, according to chemical structure, Cheah & Ramli [63] identified the important oxide compounds that demonstrated the suitability of sawdust ash as a cement substitute, specifically silica (SiO_2), alumina ($Al2O_3$), ferrous oxide (Fe_2O_3), and lime (CaO), which differs based on the kind of trees.

Table 2 shows that using SDA as a cement substitute is justified by the requirements of ASTM C-618 [66], which showed that SDA has a fair chance of working as a pozzolanic material.

4.2 Mineralogical properties

By using an X-ray diffraction investigation, Elinwa and Ejeh [67] discovered that sawdust ash when incorporated in concrete mixture contains more silicon dioxide (SiO_2) than the other reactive species, as depicted in Fig. 4. It serves as the primary gauge of pozzolanic activity. As a result, it can be utilized in place of regular Portland cement while making concrete.

SDA met with ASTM C-618's requirement that the amount of $SiO_2 + Al_2O_3 + Fe_2O_3$ be between 70% and 80%, according to Chowdhury et al. [11] as well as Raheem et al. [68]. As a result, sawdust ash has a strong propensity to function as a pozzolanic substance.

4.3 Engineering properties of sawdust ash and composites made from sawdust

4.3.1 Bricks, mortar, and concrete blocks made of sawdust and sawdust ash

In an effort to develop environmentally friendly and less expensive blocks that use raw or sawdust ash, numerous investigations have been conducted. Mangi et al. [61] provide an outstanding assessment of 17 experiments on concrete masonry blocks that were carried out amid 2012 and 2016 in 11 different nations.

According to Gil et al. [69], sawdust ash improved the post-cracking of brick masonry. The use of sawdust ash in plaster mortars was researched by Claudiu [27]. The study revealed crucial characteristics of gypsum mortars, including their potential for excellent acoustic and heat insulation and their resistance to burn by open flame. Therefore, it was recommended to use these mortars in building interior walls.

In order to increase environmental sustainability, Kupolati et al. [70] looked at the idea of producing bricks out of sawdust rather than crusher sand, in substitutions of 1%, 3%, and 5% by mass of crusher sand. When tested for compressive strength, the on-site constructed sawdust-sand bricks missed the mark of the tiniest values of 4.0 MPa recommended by SANS 10,400 [71] for strong masonry walls. The bricks' norm compressive strength at 28 days equaled 0.67 MPa, 0.23 MPa, and 0.21 MPa for the corresponding sawdust surrogate ratios of 290 × 150 × 90 mm bricks. However, using the aforementioned relative sawdust substitute ratio, the brick cubes of 100 × 100 × 100 mm produced from the lab achieved mean compressive strengths of 6.10 MPa, 5.73 MPa, and 3.7 MPa. This was attributable to enhanced quality control procedures used in the laboratory.

Ravindrarajah et al. [72] examined blocks manufactured from cement, fly ash, calcium chloride, Softwood sawdust, grit, and water to assess the possible usage of sawdust in blocks. The density and 28-day compressive strength of a sawdust cement block combination having 12% sawdust by mass were 1540 kg/m^3 and 14 MPa, respectively. However, strength was maintained at all ages, shrinkage increased considerably when calcium chloride was used. According to the study, sawdust makes an excellent replacement for lightweight blocks.

Dadzie et al. [73] used sawdust fractions ranging from 10 to 40% with a ratio of water cement of 0.5 to examine the effects of substituting sand with sawdust in a sand-cement block composition. The compressive strengths of the tested sawdust composite blocks surpassed the basic BS 6073 [74] norm of 2.8 MPa for surrogate of no more than 10%. It was additionally logged that the sawdust

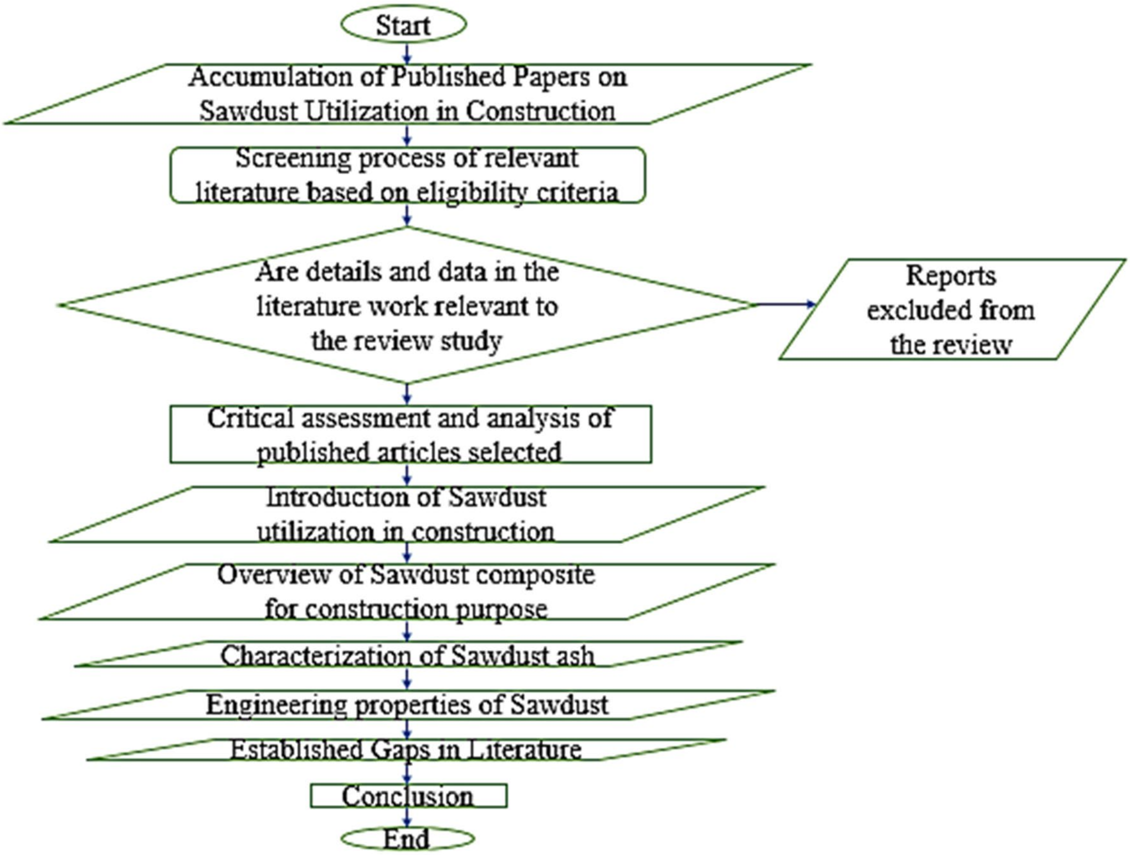


Fig. 2 Review methodology flowchart

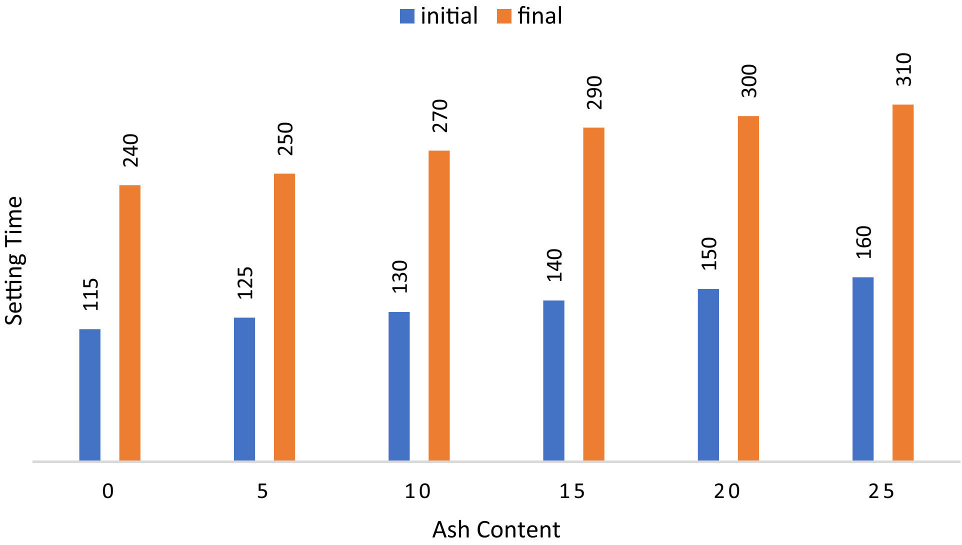


Fig. 3 Setting period of SDA v OPC paste [61]

replacement percentage shouldn't be higher than 10% for sawdust blocks to comply with standards.

Boob [75] claimed that mixing cement to sand and sawdust at a ratio of 1:6 (85% sand + 15% sawdust) achieved the best and expected results for sandcrete blocks constructed by partially substituting sawdust for sand. Blocks of 100 × 100 × 100 mm produced a compressive strength of 4.5 MPa for this mix percent. When

Table 2 Basic Oxides in SDA from several types of wood

Category of SDA Species	SiO_2	Al_2O_3	Fe_2O_3	CaO	Ref.
Pine	9.71	2.34	2.10	48.88	[63]
Ork	29.93	4.27	4.20	15.56	[63]
Alder-fir	37.49	12.23	8.09	26.41	[63]
High calcium rubber	2.70	1.30	1.30	61.0	[64]
Rubber	9.91	1.19	1.63	40.23	[65]

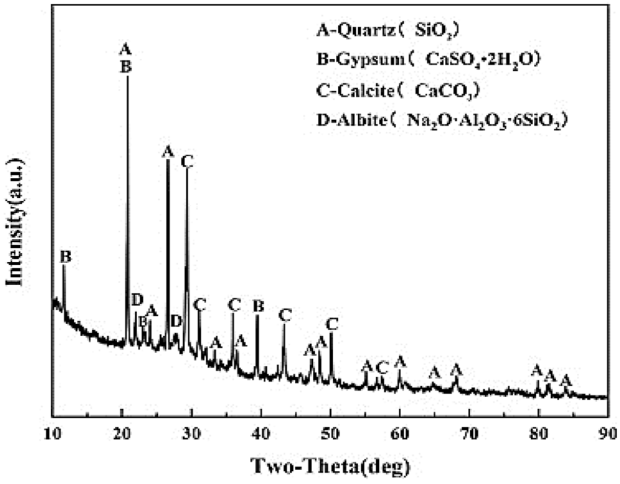


Fig. 4 XRD analysis of sawdust ash mixture inconcrete [67]

compared to the minimal standard of 2.8 MPa stated in BS 6073 [74], this is an excellent result for blocks constructed with no more than a 10% substitution of sawdust.

In a different study by Turgut and Algin [76], wood dust (WD) from the cutting of raw wood and limestone powder wastes (LPW) from quarrying processes were combined to produce WD-LPW bricks. International standards like BS 6073 [74], and BS 1881 [77] were met by the compressive strength, flexural strength, unit weight, workability, ultrasonic pulse velocity (UPV), and water absorption values produced by the bricks with different WD-LPW combinations. The outcomes meet the criteria set out by BS6073 for construction material to be employed in structural functions. This was researched as a possible wall building material, a wooden board alternate, and a less expensive option to concrete blocks, ceiling panels, and soundproofing materials.

Moreira et al. [78] tested the efficacy of building blocks manufactured from sawdust from the Dinizia Ducke hardwoods used as a partial replacement for fine aggregates. The blocks were created by adding sawdust at a weight-replacement ratio of 5% to fine aggregates. The sawdust was treated using two different methods: one involved washing it in lime, an alkaline solution, and the other involved submerging it in aluminum sulfate. On day 28, the results for the two treatment methods' compressive strength were 1.39 and 3.98 MPa, respectively. In terms of water absorption, the outcomes showed 13.13 and 10.40%, respectively. According to the outcomes, blocks made from sawdust treated with aluminum sulphate performed better than blocks made from sawdust treated with an alkaline solution. The study found that sawdust from Dinizia Ducke treated with aluminum sulphate may substitute 5% of the fine aggregates in masonry blocks.

When making hollow sandcrete blocks, Adebakin et al. [79] looked at the potential of substituting sawdust for portion of the sand. The study's objective was to lower the cost of construction products as well as the dead loads placed on structures, especially tall buildings and structures constructed on fragile soils. The experiment revealed that replacing 10% of the sand with sawdust produced blocks of sandcrete with compressive strengths that were remarkably close to the Nigerian technical requirements of 3.5–10 MPa. Blocks with a 10% weight loss and a 3% decrease in production costs are produced as a result of this 10% sawdust replacement composition.

Lightweight bricks constructed from 3:2 and 2:1 sawdust to cement mixtures were evaluated by Zziwa et al. [80]. 100 mm bricks of each dimension were evaluated as samples that had been air dried and samples that had been soaked in water for 24 h at room ambient. The arid samples having a sawdust to cement mix of 3:2 generated the highest compressive strength value of 2.21 MPa. And for wet specimens, the matching compressive strength value was, on average, 1.38 MPa. The bricks did not meet the requirements for usage in load-bearing buildings as well as walls susceptible to wet environments because of their low compressive strength. Alternatively, they could be utilized for interior wall paneling in environments with little to no loading and little to no moisture. Table 3 displays the compressive strengths of various sawdust bricks and blocks. The results show that sawdust brick/block composites are effective, which ought to inspire optimism in continued application for construction.

4.3.2 Lightweight concrete made of sawdust and sawdust ash

Table 4 summarizes the literature reviews of a few publications that have been published between 2011 and 2016. It displays earlier research on SDA that was done to create a lightweight, affordable, long-lasting, and ecologically friendly material for the building sector. In order to prevent environmental pollution and provide sustainable building materials for the construction of competitively cost structures, it was discovered that employing SDA has a diverse range of uses. One of such is the replacement of cement and sand in concrete.

4.3.2.1 Use of sawdust in place of sand in concrete mix

Osei and Jackson [84] investigated sawdust concrete utilizing sawdust, pulverized granite, and conventional cement. According to the study, sawdust can be utilized as an aggregate to create non-structural lightweight concrete that can be applied in conditions where compressive strength is not a key factor. Supplementary study of the compressive strength revealed that concrete with less than 14% sawdust replacement may have a 28-day compressive strength of 20 MPa. 10% sand replacement with sawdust increased compressive strength from 23.24 up-to 27.31 MPa within 7 and 28 days, according to the study of Bdeir [85], demonstrating that partial sand replacement using sawdust in concrete could actually accomplish same order of strength as conventional concrete during extended curing times.

Sawdust concrete was prepared by Suliman et al. [86] using cement, sand, broken stones, and sawdust. Investigations were done to examine what would happen if 5% upto15% of the sand content were replaced with sawdust. After 28 days, the ultimate compressive strength readings were 50.06 MPa, 41.48 MPa, and 34.7 MPa. 10% replacement sawdust was found to be the ideal amount for producing sawdust concrete. The research also revealed that the sawdust concrete did not contain any dangerous health hazards.

Following a report by Oyedepo et al. [87], with a water/cement proportion of 0.65 and partial substitutions of 0%, 25%, 50%, 75%, and 100% sawdust to fine sand, a 1:2:4 mix proportion was created. The sawdust replacement percentages of 25%, 75%, and 100% had compressive strengths of 14.15 MPa, 12.96 MPa, and 11.93 MPa. From the research, it was found that adding sawdust to concrete in a proportion more than 25% has a negative impact on the material's strength and density. Another argument made was that adding 0–25% sawdust as a partial substitute wouldn't have a negative impact on the strength of the concrete.

Sawdust has been demonstrated to be a promising material for the manufacture of low weight concrete [88]. The compressive strengths of fine aggregate decreased in an experiment by Tilak et al. [20] when sawdust was substituted at amounts of 10%, 20%, 50%, and 100%, the result obtained were 24.13 MPa, 15.55 MPa, 11.11 MPa, and 8.13 MPa respectively. This two research suggest the possibility of using sawdust in structural concrete as long as it doesn't replace more than 10% of the sand.

Chitra and Hemapriya [89] reiterated the idea of utilizing sawdust as a substitute for sand with the best strengths attained at 15% substitute of sand with sawdust using a mix ratio of 1:1.60:2.78.

In their investigation on sawdust concrete, Sawant et al. [90] included cementitious metakaolin. This additive was intended to improve the connection between the sawdust and the other concrete constituents. In the experiment, sand was substituted with sawdust in fractions of 0%, 5%, 10%, 15%, 20%, and 25%, for sawdust concentrations under 10%, adequate compressive strength was attained.

Awal et al. [91] probed samples of sawdust concrete prepared with cement to sawdust fractions of 1:1, 1:2, and 1:3. the corresponding compressive strength values at age 28 days was 18.65 MPa, 17.20 MPa, and 12.80 MPa. With extended cure times, sawdust concrete became more durable. On the other hand, when the mixture's sawdust content increased, the strength and reported modulus of elasticity fell.

Ogundipe and Jimoh [22] conducted research on sawdust concrete, which was formed from 1:1:2 and 1:1.5:3 combinations utilizing sawdust in place of the coarse material. Their compressive and flexural strengths after a period of 28 days were respectively 18.33 and 8.78 MPa and 1.71 and 1.33 MPa. The 28-day linear shrinkages of the mixtures were, respectively, 0.67%, 0.50%, 1.83%, 1.83%, and 1.95%, whereas the 28-day water absorption rates were, respectively, 5.69%, 8.97%, 8.29%, 7.83%, and 11.11%.

Sojobi [92] claims that by substituting sawdust residues and laterite for fine aggregate and cementitious material, respectively, it is possible to create lightweight interlocking concrete pavement units that are environmentally beneficial. The same components were employed by Sojobi et al. [93] to make extremely lightweight green interlocking pavement units. The paving units achieved a compressive strength of 16.6 MPa with an ideal sawdust content of 10% and showed a toughness of 64.5 pendulum significance level following 90 days of water curing.

Olutoge [94] investigated the use of reinforcing in sawdust concrete. This study showed that substituting sawdust below 25% of the sand in reinforced concrete produced results that satiated the BS 8110[95] specified standards for strength characteristic for structural application of concrete.

A summary of the 28-day compressive strength data for sawdust concrete in connection to the partial substitution of sand by sawdust in various concrete combinations is shown in Fig. 5 [84, 86, 88–90, 94]. Neville [96] recommended that concrete with compressive strengths more than 15 MPa is typically produced when sawdust is substituted for sand in concrete mixes of 5–15%.

Figure 5 shows that combinations that substitute amid 5% and 10% sawdust for sand can yield concrete having compressive strengths greater than 20 MPa. As a result,

Table 3 Results of Compressive strength of sawdust blocks or bricks from different literatures

Author	Size and type	Sawdust composite mix	Compressive strength at 28 Days
[70]	100 × 100 × 100 mm cubes	Sand, sawdust, hardener, cement, and water were all utilized in the order: 13%, 2%, 11%, 73%, and 1%, respectively.	Brick cubes (100 × 100 × 100 mm) had an optimal compressive strength on average of 6.10 MPa in the testing facility. The specification for solid masonry units in masonry walls calls for a minimum value of 4.0 MPa. [51]
[72]	100 mm dia. × 200 mm high cylinders	Sawdust amounts ranging from 3–12% in fly ash, cement, sand, calcium chloride, lime, and water mixtures.	13 MPa was created from 12% sawdust, which resulted in concrete with a density of 1520 kg/m3.
[73]	100 × 100 × 100 mm cubes	Sand, Sawdust, and cement are batched by volume at a mix ratio of 1:6 and a constant water cement ratio of 0.5. 10%, 20%, 30%, and 40% sawdust was substituted for the sand	A 3.04 MPa strength at 10% replacement. (higher than the minimum BS 6073 pressure of 2.8 MPa)
[75]	100 × 100 × 100 mm cubes	0%, 5%, 10%, 15%, & 20% substitution of sawdust in the ratio of 1:4 (cement: sand + sawdust) 1:6 (replacement of 0%, 5%, 10%, 15%, and 20% sawdust) 1:8 (replacement of 0%, 5%, 10%, 15%, and 20% sawdust)	at 15% replacement of sand by sawdust, 1:6 (cement: sand + sawdust) mixture yielded a strength of 4.5 MPa.
[76]	105 × 90 × 75 mm blocks	Cement, water, and three different ratios of waste wood sawdust and limestone powder waste (WSW). In the WSW-LPW combination, WSW replacements of 0%, 10%, 20%, and 30% were employed.	WSW replacements at 0%, 10%, 20%, and 30%, respectively, produced 24.5, 16.6, 11 and 7.2 MPa.
[80]	50 × 50 × 50 mm and 100 × 100 mm cubes	Both sizes made with sawdust to cement ratios of 3:2 and 2:1	Using sawdust to cement ratios of 3:2 and 2:1, respectively, and 50 × 50 × 50 mm blocks, a mean compressive strength of 1.61 MPa and 1.99 MPa was produced, and for the 100 × 100 mm blocks, a mean compressive strength of 1.78 MPa and 2.21 MPa was obtained.

Table 4 Application of SDA as replacement of material component in concrete

References	Country	Materials	Design and mix ratio	Study results
[11]	India	Ash produced by uncontrolled sawdust burning	5, 10, 15,18 and 20% w/b: 0.4 and 0.45 curing phase 7 and 28 days	Strength marginally declines as wood ash content rises.
[15]	Malaysia	OPC, Silica fume, Rubber wood ash with SP dosage 0.5 to 3.0	3. 7, 28, 90, 180, and 364 days for curing 7% silica seethe with a w/b ratio of 0, 2, 4, 6, 9, 12, 15, 18, 21, and 27%.	Silica seethe with OPC and 6% wood ash provides better compressive strength when compared to OPC.
[16]	Nigeria	Ash produced by unattended sawdust burning and through 600 µm	1:2:4 mix ratio with 0, 5, 10, 15, 20, 25 and 30% SDA, curing period was for 7, 14 and 28 days	At 15% cement replacement with SDA, the 28-day compressive strength was measured at 19.05 N/mm2, a 32% improvement in strength over the control mix.
[63]	Malaysia	wood ash made from various species	Replacement of 0%, 10–40% for SDA was used, w/b ratio: 0.60, curing periods: 7, 18, 91, and 180 days	Using wood ash as a cement substitute in concrete up to 25% of the binder weight has no adverse consequences.
[64]	Malaysia	OPC, Silica seethe, Rubber wood ash with SP dosage 0.4 to 2.6	binder: sand 1:2.25 with 7.5% Silica seethe was used with 0, 4, 6, 8, 10, 12, & 16% replacement, w/b ratio: 0.32 and a curing phase of 3, 7 and 28 days	Cement can be replaced by wood ash up to 16% of the weight of the binder, which is equivalent to a negligible quantity (7.5%) of DFS. This improves the cement matrix's pore structure and reduces the chloride diffusivity in mortar.
[68]	Nigeria	SDA was made via uncontrolled burning and sieving through a 425 µm mesh.	1:2:4, with 5%, 10%, 15%, 20% and 25% by weight of OPC was used, w/b ratio 0.5–0.6, and curing period was for 3, 7, 28, 56 and 90 days	SDA concrete's compressive strength started out weak but improved significantly over the next 90 days. With 5% SDA replacement at 90 days, the ideal compressive strength value was obtained as 23.26 N/mm2.
[78]	Brazil	Hallow block properties (size not mentioned)	5% by weight of sand in 1:2.5:2.5, 1:3.5:3.5, 1:4:4 and 1:5:5 concrete mixes were used, water curing period was for 7 and 28days	Trial tests for the mass unit proportion were conducted using various ratios of fine and coarse aggregates (20/80, 25/75, 30/70, 35/65, 50/50, and 60/40), with the 50/50% showing promising results. Proportion of 1:4:4was found economical, and at 28 days, 6.45 MPa compressive strength was noted.
[81]	Ghana	Solid block properties of (100 × 100 × 100 mm)	Sand in a 1:2 mixture at 0, 20, 40, 65, 80, and 100% by weight was used. 7, 14, and 28 days of water curing was also used.	The ideal ratio of sawdust to sand was discovered to be 20%, and at 28 days, flexural strength was measured to be 15.9 N/mm2.
[82]	India	SDA was gathered from various lumber mills and was retained on sieves measuring 45 µm, 12, 23, 40, 60, and 90%.	5%, 10%, 15%, 20%, 25% and 30% by weight of OPC and the curing period ranged 3, 7 and28 days	Utilizing wood ash as an OPC replacement lowers the slump values of concrete and even raises water consumption. For structural grade concrete, 10% binder replacement by weight has been found to be effective.
[83]	India	Solid Blocks properties of (100 × 100 × 100 mm) and Cylinders Ø100mmx200mm)	0, 5, 10, 15 and 20% by weight in concrete, mix ratio of 1:1.44:3.16 was adopted water curing period was 7 and 28days	The average results for compressive strength at 28 days were 27.78, 25.24, 21.42, 16.44, and 10.58 N/mm2, respectively when the sand is replaced with sawdust at 0, 5, 10, 15, and 20%. Tensile strength measurements at 28 days yielded an average of 3.18, 3.11, 2.55, 1.77, and 1.36 N/mm2. The best and most cheap concrete was found to include 10% sawdust.

these combinations are compliant to ASTM C330/C330M-09 [97] standards and are suitable for structural applications. When sawdust concentration surpasses 15% of the sand replacement percentage, compressive strength is noted to drop down quickly.

Figure 6 below shows how flexural strength decreases as sawdust content rises. In particular, investigations by Sawant et al. [90], Olutoge [94], Sasah and Kankam [98] make this clear.

Additional analyses have been done whereby sawdust constitutes part of the main components of the concrete mix. Table 5 compares the findings of the compressive, split tensile, and flexural strength of sawdust concrete of different experiments. The tabulated findings show that concrete's compressive, flexural, and split tensile strengths decrease as sawdust content rises. Table 5 further indicates how a 1:1:2 and 1:1:1 mixture generated good compressive strength that can be used for lightweight concrete.

4.3.2.2 Use of sawdust ash (SDA) as replacement of cement Udoeyo, Dashibil, and Marthong [102, 103] studied concrete made using sawdust ash (SDA) to partially replace traditional cement. It was noted in the study that a 10% SDA substitution at 28 days achieve a design strength of 20 MPa, which is akin to the strength achieved by traditional concrete at lengthier curing durations. Marthong [103] observed that using SDA as a substitute of cement tends to make concrete less durable when exposed to a sulfate environment. Obilade [16] showed that SDA achieved 28 day compressive strengths between 21.02 and 19.05 MPa at various sawdust ash percentage replacement. The ideal SDA replacement for cement was therefore assumed to be between 5% and 15% SDA because SDA levels above 15% considerably lowered the compressive strength of concrete.

Using 1:1:2 concrete control mix, Dhull [104] substituted percentages of 5%, 10%, 15%, and 20% for the mass of cement. The compressive strengths of the 5% and 10% replacement contents were measured at 32.44 MPa and 30.24 MPa, accordingly, after 28 days. Concrete was produced with compressive strengths lesser than the strength of the control mix when cement was substituted with SDA levels more than 10%.

Scheffe's Simpexfive prototype proportion of 0.5:0.95:0.05:2.25:4 was utilized in a study by Onwuka et al. [105] to produce SDA concrete having an ideal compressive strength value of 20.44 MPa at 28 days. In this ratio, water, cement, sawdust ash, sand, and granites are all same. According to the study's findings, sawdust concrete can be successfully employed in the construction sector.

According to Fapohunda et al. [106], using wood waste as SDA, or sawdust, in a suitable concrete mix design can provide structural concrete that conforms with building conditions. SDA content, nevertheless, cannot outstrip 20%. According to Mangi et al. [107], SDA-infused concrete exhibits strong durability traits against the vast majority of procedures that diminish the lifespan of concrete. However, its longevity is compromised by exposure to carbonation and sulfate assault. Further investigation into the sturdiness of high-strength concrete produced with SDA in hostile alkaline and acidic environments is also required.

Raheem et al. [68] also discovered that when the SDA component increases, SDA concrete loses workability. This implies that SDA needs more water than ordinary Portland cement. The study found that 5% SDA was the optimal replacement level, to achieve a level comparable to that of the control mix, which included 0% SDA. SDA can be employed to make concrete having compressive strengths over 20 MPa by replacing cement with it in percentages ranging from 5 to 15%, as shown in Fig. 7. This concrete can be used in structural applications.

Figure 8 illustrates Elinwa and Mahmood's [62] observation that, when the strength parameters are taken into account, the compressive strength at 28 days of 5, 10, and 15% cement replacement is around 93, 78, and 68% of the control mix, respectively. When 10% OPC is substituted, SDA demonstrates the desired workability and good strength performance.

It was noticed that the appropriate limit for replacing cement with wood ash is 10–20% by volume of the binder. Additionally, early aging of concrete containing SDA reduced compressive strength, whereas prolonged curing times greatly increase it. It was also discovered that wood ash at 16–20% replacement continued to generate good strength mortar with compressive strength over 55 N/mm^2 at 364 days during the long-term curing phase [15]. Additional research is needed, according to Chowdhury et al. [11], to improve the strength and longevity of concrete.

4.4 Thermal properties of sawdust composite

Materials' thermal conductivity and thermal transmittance characteristics demonstrate their capacity for thermal insulation. Building materials having thermal conductivities less than 0.07 W/mK are referred to as thermal insulators [108].

When compared to other building materials, timber has better thermal conductivities. Timbers with lower densities have lower conductivities, and they vary slightly depending on species, moisture levels, and densities. One of the main advantages of wood waste according to Meyer [42], is its low weight and excellent thermal insulating value.

When cement, sawdust, and sand were combined in the following ratios: 1:1:1, 1:2:1, and 1:3:1 it was found that the 1:3:1 admixture had low thermal conductance compared

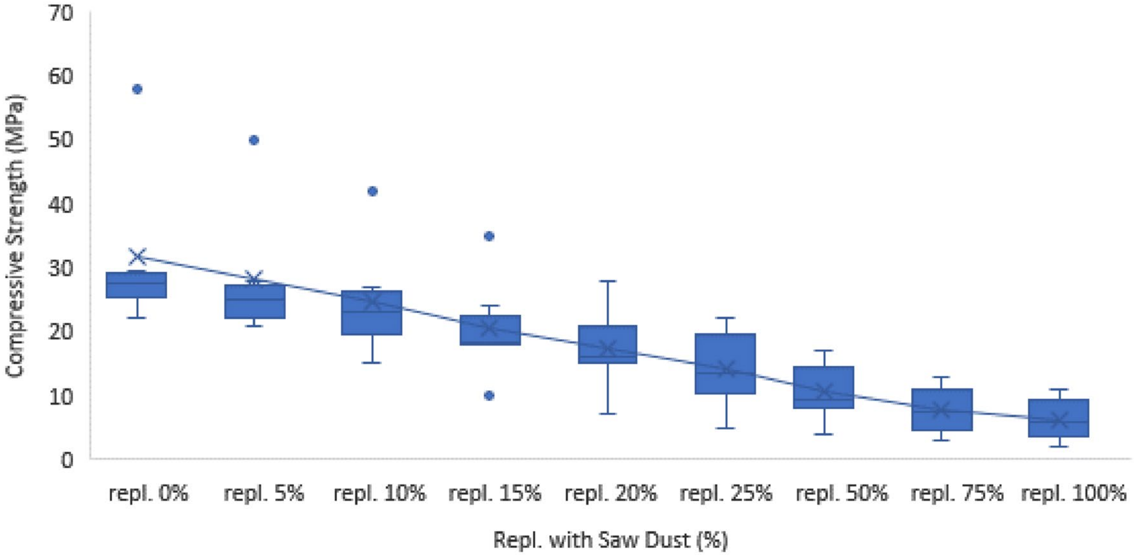
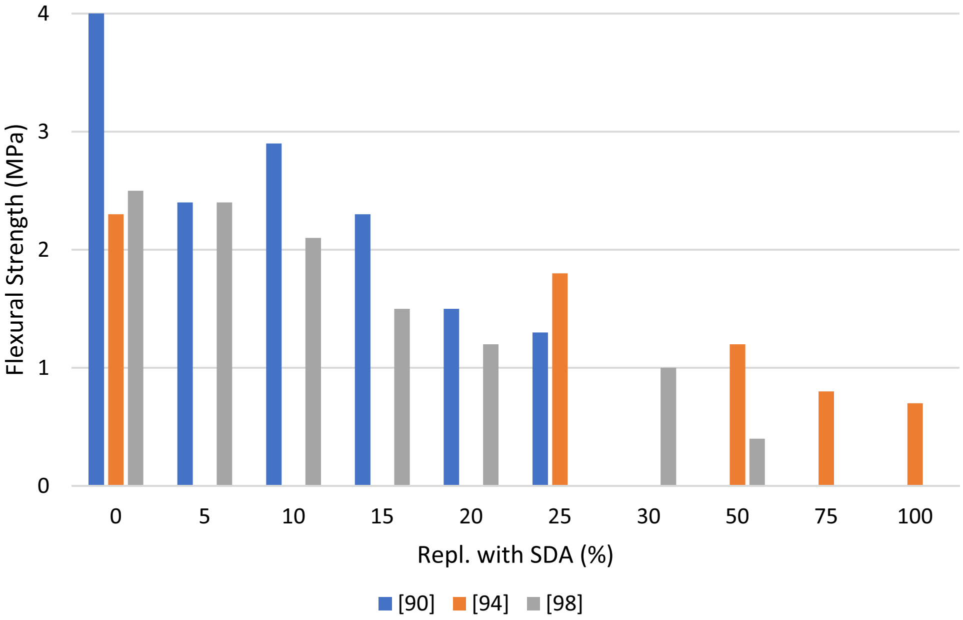


Fig. 5 Compressive strength of sawdust concrete by replacing sand with sawdust [84, 86, 88–90, 94]

Fig. 6 Test of sawdust concrete by replacing sand with sawdust [90, 94, 98]



to the other mix. Because there is more sawdust in the 1:3:1 mixture than in the other two, there is less heat transfer through that mixture [100, 109].

With a cement to sand ratio of 1:2.5, Salih and Kzar [110] substituted sawdust and pre-treated reed for natural sand. Reed and sawdust were pre-treated in boiling water with lime, adding weight that was 20% more than the original ingredients. The toxic soluble carbohydrates, tannins, waxes, and raisins were reduced by soaking procedure. 10%, 20%, 30%, and 40% mixtures of sawdust and reed were used as replacement material, respectively. A water cement proportion of 0.4 was maintained for all of the mixes. The 28-day oven dry density values, which varied from 2060 to 1693 kg/m^3, had the high values, which correspond to the density of the control mix. The 40% sand replacement component resulted in the lower density values. Both the control and the 40% sand replacement mix's thermal conductivity dramatically dropped, going from 0.745 to 0.222 W/mK, accordingly.

A study by Sindanne et al. [111] found that the amount of cement and lime used as stabilizing agents increased thermal conductivity in earth blocks stabilized by cement,

Table 5 Strengths of various sawdust mix composites, including their compressive, flexural, and split tensile properties

Author (s)	Mix (cement-sand- sawdust)	Compressive strength at 28 days (MPa)	Flexural strength at 28 days (MPa)	Split tensile strength at 28 days (MPa)
[91]	1:1*	18.65	2.75	2.06
	1:2*	17.20	2.20	1.95
	1:3*	12.80	1.90	1.30
[99]	1:1:2	18.33	1.71	–
	1:1.5:3	8.78	1.33	–
[100]	1:1:1	14.00	4.00	4.00
	1:1:2	6.00	2.90	2.2
	1:1:3	4.00	0.50	0.40
[101]	1:1:1	10.861	2.32	1.98
	1:2:2	9.126	2.09	1.71
	1:3:3	4.471	1.89	1.58

*Ratio of cement to sawdust; –Unavailable data

sawdust, and lime. However, the blocks' heat conductivity was decreased by stabilizing them with sawdust. As a result, it was discovered that blocks stabilized with sawdust were more heat resistant than blocks stabilized with cement or lime.

Sawdust was used in place of coarse aggregate in four different mixtures, including 1:1:2, 1:1.5:3, 1:2:4, 1:3:6, and 1:4:8 by Ogundipe and Jimoh [99]. Following a 28-day curing period, the corresponding conductivity measurements were 0.229, 0.232, 0.229, 0.223, and 0.176 W/mK. The findings show that as sawdust concentration increases, thermal conductivity gradually decreases. Figure 9 [110–113] also revealed this pattern. Figure 9 further demonstrates that sawdust concrete has less thermal conductivity than normal concrete (in this instance, with 0% sawdust content). The findings of Asadi et al. [114] supported the observation that heat conductivity decreases with increasing amounts of sawdust. Normal concrete has a density between 2100 and 2400 kg/m3 and a thermal conductivity of 1.40 and 1.75 W/mK [115, 116]. The thermal conductivity of the resulting lightweight concrete was dramatically reduced when sawdust was added to the concrete mixture. The ASTM C332-09 [117] standards, which stipulates that the total peak for thermal conductivity of lightweight concrete should be 0.43 W/mK with a density of 1440 kg/m3 at 28 days, are also met by the thermal conductivity results in Fig. 9.

4.4.1 Comparison of thermal properties of sawdust-based construction materials with aerogels

Sawdust-based construction materials and aerogels both have unique thermal properties, but there are some differences between them [118, 119];

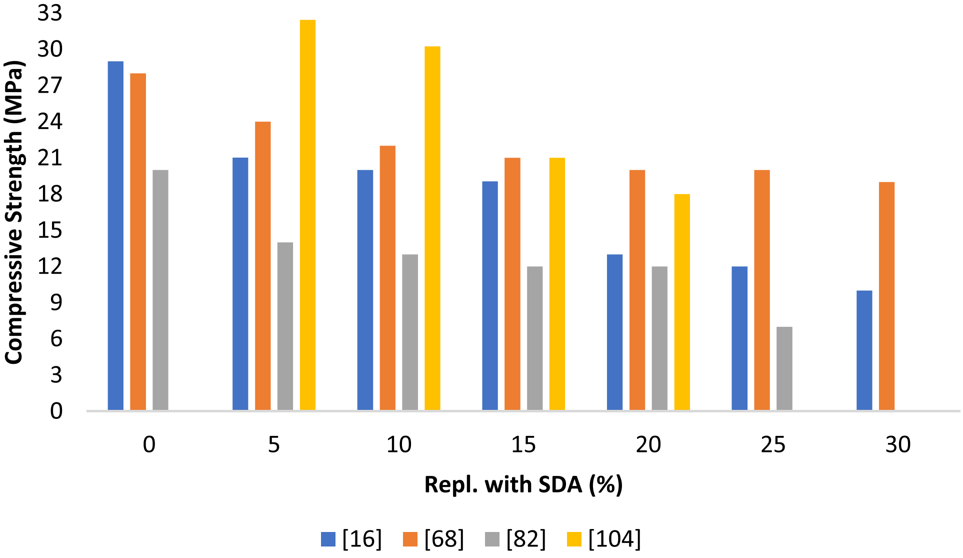


Fig. 7 Effects of varying SDA proportion on the compressive Strength properties [16, 68, 82, 104]

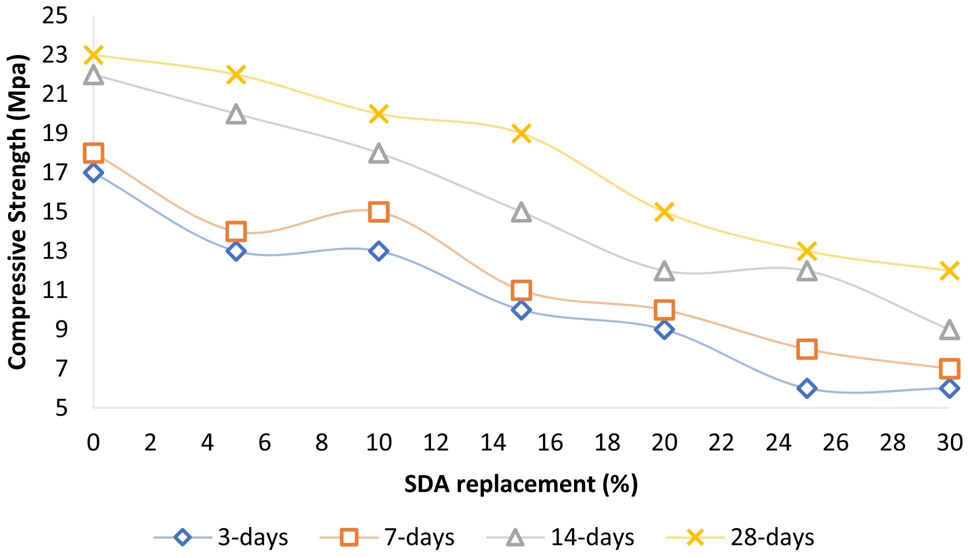


Fig. 8 Comparative effects of different hydration periods on the compressive strength of concrete mixed with varying proportions of SDA [62]

4.4.1.1 Thermal conductivity Aerogels have an extremely low thermal conductivity, which means they are excellent insulators. In contrast, sawdust-based materials have a relatively higher thermal conductivity, but still provide good insulation properties compared to traditional building materials like concrete or steel.

4.4.1.2 Temperature range Aerogels are capable of insulating in a wider range of temperatures, including high-temperature applications. Sawdust-based materials are better suited for lower temperature ranges and may not be suitable for use in high-temperature environments.

4.4.1.3 Density Aerogels have a very low density, which makes them ideal for lightweight insulation applications. Sawdust-based materials are typically denser than aerogels, but still lighter than many traditional building materials.

4.4.1.4 Cost Aerogels are more expensive than sawdust-based materials, which can make them less cost-effective for some applications.

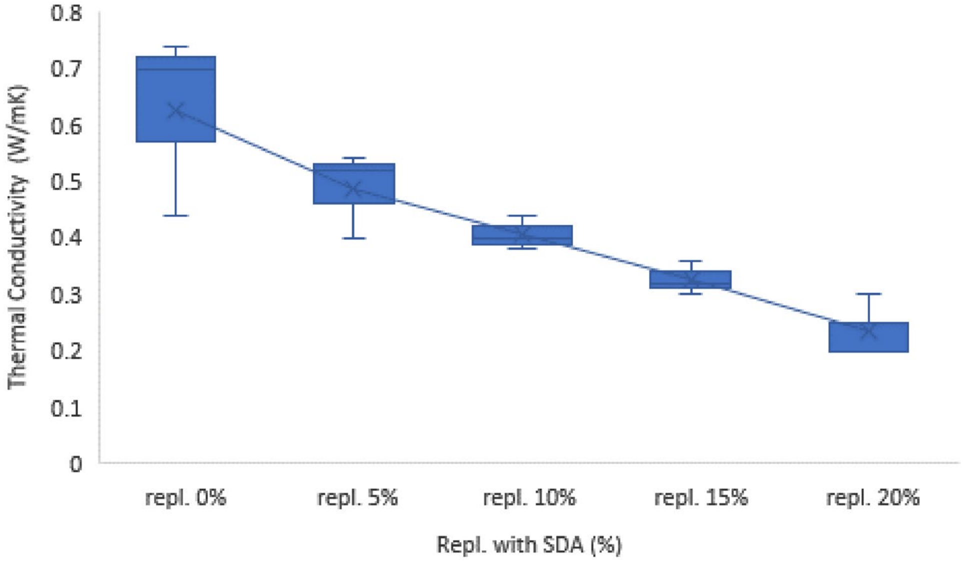
4.4.1.5 Sustainability Both sawdust-based materials and aerogels are sustainable options, as they are made from renewable resources and have a lower environmental impact than traditional building materials.

Overall, aerogels are better insulators than sawdust-based materials, but they are also more expensive. Sawdust-based materials may not be suitable for high-temperature applications, but they offer a more affordable and sustainable alternative for low to moderate temperature insulation. The choice between the two depends on the specific application and the balance between cost, performance, and sustainability.

4.5 Sound properties of sawdust composites

Along with pollution of the air, water, and solid waste, sound is one of the four major ecological concerns. Sound absorption materials are necessary to reduce the negative impacts of noise pollution on human health, such as stress and hearing loss [120]. For those who are sensitive to its effects, infrasonic noise, particularly those that has frequency ranging between 10 and 100 Hz, may raise anxiety. [121]. The acoustic component of a sound wave loses energy as it travels through things that absorb sound. Measuring the absorption properties, which is the amount of acoustic energy absorbed by the material upon the incidence of the energy wave, is one method for assessing the effectiveness of acoustic materials [122, 123]. A sound absorption value near to 1.00 indicates good sound absorption for a sound bandwidth of 125 to 4000 Hz [122, 124]. When the absorption coefficient is 0, no sound has been absorbed. The most popular material for sound absorption in auditoriums is wood. Rice hull-sawdust composite boards can be used as an alternative to traditional materials for sound absorption in quasi buildings like ceilings, wall sheathing, and interior wall surfaces [125]. Tiuc et al. [124] studied the effectiveness of recycled rubber and sawdust as sound-absorbing materials. One item included 15% polyurethane binder and recycled rubber powder. The other was made up of 30% polyurethane and 70% sawdust. Both goods have a 15 mm thickness. For frequencies between 100 and 1000 Hz, the sound absorption coefficient properties of both objects were the same. For the higher frequency

Fig. 9 Thermal conductivity of concrete produced from sawdust [110–113]



range of 1000–3150 Hz, the sample containing rubber particles demonstrated superior sound absorption properties. In addition to being evaluated, the acoustic properties of goods formed from recycled rubber granules and sawdust were compared to those of glass wool and the existing commercially available flexible polyurethane foam. Experimental testing of the sound absorption coefficient was done between the frequencies of 100 and 3200 Hz. The outcomes demonstrated that composite materials manufactured from rubber granules and sawdust outperformed those made from competing materials, notably at frequencies below 1600 Hz. In the frequency range of 300 to 3150 Hz, the sawdust and 30% urethane rubber material had a low sound absorption coefficient of 0.65. At a frequency of 2000 Hz, high sound absorption factor of 0.979 was noted [123]. Additional comparisons between products created with 100% Flexible Polyurethane Foam and products produced using 50% Fir Sawdust and 50% Flexible Polyurethane Foam were done by Tiuc et al. [126]. Between 100 and 1700 Hz, the 100-FPF device suppressed sounds well. At 1700 Hz, this product's highest sound absorption coefficient was 0.86. With a maximum sound absorption coefficient value of 0.89 at a frequency of 700 Hz, the 50-FPF product demonstrated effective sound absorption qualities for the frequency range of 100 to 700 Hz. With this study, complicated sound-absorbing properties in composite porous materials were revealed. The properties of several types of materials' sound absorption are shown in Table 6, this clearly demonstrates that sawdust composites are superior to conventional concrete and masonry at absorbing sound.

4.5.1 Sound wadding

Products for sound enthrallment eliminate resonates within a space, stopping sound from reverberating. On the other side, sound-insulating materials prevent or halt sound waves from reaching nearby spaces. Office walls with timber studs can be built to have whatever level of sound insulation needed, even at the absolute minimum. A very high sound insulation can be achieved with a minimal quantity of overall thickness with careful planning and consideration to detail [130].

Lightweight timber-based floor/ceiling systems (LTFSs) can provide better sound deadening material than systems based on concrete slabs, sand-sawdust layer's ability to effectively minimize vibrations and, as a result, insulate the sound of general composite construction over a broad range of frequencies has been proven [131]. To predict the mechanically excited vibration of LTFSs, a mathematical model was applied. The sand-sawdust layer in LTFSs was shown to have good sound-insulating qualities [54]. One issue was identified during Emms et al. [132] examination of lightweight floors: inadequate impact insulation capability in the short range of 16 to 250 Hz. When a sand/sawdust mixture is employed as a filler in the battened voids, these light floors function effectively as impact insulators. Sawdust and coconut coir fiber have been looked into as suitable noise reduction material by Chathurangani et al. [133]. The investigation's findings supported the materials' capacity for efficient noise reduction. The investigation's findings demonstrated that sawdust and coir fiber tiles had noise reduction co-efficient that ranged from 0.1 to 0.5, which assesses the ratio of noise reduction levels to incident sound intensity. The usefulness of panels made of identical materials for acoustical wall stacking in noisy urban housing was later confirmed by a study carried out in Indonesia [134].

5 Benefits and relevance of utilizing sawdust composite in construction

5.1 Benefits of sawdust concrete

In the study of Suliman et al. [86] sawdust concrete has some unique characteristics which make it competitive among other building materials;

- Sawdust Concrete is made of green, ecologically pure stuff.
- Sawdust Concrete controls interior humidity level and itis frost proof.
- Sawdust Concrete has favorable thermal and sound proofing properties.
- Sawdust Concrete is not subject to mold and fungi.
- Sawdust Concrete is light weight and can save labor &natural resources,
- It is an economical alternative to conventional building concrete method and material.
- Due to material's inert nature, it does not react with any ingredients of concrete and steel.
- At the end of its initial service life, concrete can be crushed and reused as aggregate for new concrete continuing the cycle of environmental benefits.

5.2 Relevance of utilizing sawdust composite in construction

The use of sawdust composite is relevant for several reasons;

5.2.1 Sustainability

The use of sawdust composite in construction is a sustainable alternative to traditional building materials such as concrete and steel. By utilizing a byproduct of the timber industry, it helps to reduce waste and minimize the environmental impact of construction.

5.2.2 Cost-effectiveness

Sawdust composite is typically less expensive than traditional building materials, making it an attractive option for cost-conscious builders. This can result in cost savings for construction projects.

5.2.3 Energy efficiency

Sawdust composite has excellent insulation properties, which can help to reduce energy consumption and improve energy efficiency in buildings. This is becoming increasingly important as energy costs continue to rise.

5.2.4 Versatility

Sawdust composite can be molded into a variety of shapes and sizes, making it a versatile material for construction.

Table 6 Common structural materials' sound capacity

References	Source	Coefficient of sound absorption	Units (Hertz)
[124]	Sawdust with 30% polyurethane binder	0.1–0.89	450–1600
[125]	composite boards of rice hull-sawdust	0.2 0.4 0.40–0.55	500 1000 Above 1000
[126]	50% flexible polyurethane form and 50% fir sawdust make up the composite material.	0.09–0.89	100–800
[127]	Plane unpolished concrete	0.01, 0.02, 0.05	125, 1000 and 4000 correspondingly
[128]	Brick wall, stuccoed with rough finish	0.03, 0.04, 0.07	- Ditto -
	Brickwork of dimensions 230 × 50 × 55 mm	0.04, 0.35, 0.36	- Ditto -
	panelling of tinny plyboard	0.42, 0.08, 0.06	- Ditto -
	Solid wooden door	0.14, 0.08, 0.10	- Ditto -
[129]	Sawdust and reprocessed Rubber granules	0.65 0.979	300–3150 2000

This allows for greater design flexibility and the creation of unique building designs.

5.2.5 Health and safety

The use of sawdust composite in construction can improve the health and safety of workers and occupants of the building. Sawdust composite does not produce the same level of harmful dust and chemicals as traditional building materials, which can be harmful to human health.

In summary, the utilization of sawdust composite in construction is relevant due to its sustainability, cost-effectiveness, energy efficiency, versatility, durability, and improved health and safety.

6 Challenges and future trends

6.1 Challenges

While sawdust can be used as a sustainable construction material, there are several challenges that must be overcome to make its utilization more widespread. Listed below are some of the challenges.

I. Fire resistance: Sawdust is combustible and can pose a fire hazard. Special additives and treatments are required to improve the fire resistance of sawdust-based materials.
II. Durability: Sawdust-based materials may not be as durable as traditional building materials like concrete or steel. They can be susceptible to decay, insect damage, and moisture absorption. Protective coatings and treatments are required to improve the durability of sawdust-based materials.
III. Strength and stiffness: Sawdust-based materials may not have the same strength and stiffness as traditional building materials. They may require reinforcement with other materials or additives to improve their structural properties.
IV. Limited applications: Sawdust-based materials may not be suitable for all construction applications. They are primarily used as insulation or filler materials and may not have the required properties for load-bearing or high-stress applications.
V. Availability and consistency: Sawdust is an agricultural by-product and its availability and quality may vary depending on the source and processing methods. This can affect the consistency and quality of sawdust-based materials.
VI. Perception: Sawdust-based materials are still relatively new and may not be widely accepted by the construction industry or consumers. This can create a perception challenge that needs to be overcome to promote the adoption of sawdust-based materials.

Overall, sawdust-based materials have the potential to be a sustainable alternative to traditional building materials, but they face several challenges that need to be addressed to make their utilization more widespread. These challenges include fire resistance, durability, strength, limited applications, availability, and perception.

6.2 Future trends

In many nations that produce timber, sawdust is a raw material that is easily accessible and a recyclable waste. When compared to the energy and money needed to utilize natural resources, it may be collected and delivered at a low cost. By giving this garbage value by turning it into construction composites, we can meet the demand for environmentally friendly and cost-effective materials for construction, and generate employment. Therefore, it is anticipated that research and development into sawdust building composites would expand soon. Future research and development efforts could focus on developing adaptive sawdust construction composite materials that are more robust, durable, lightweight, energy-efficient, and inexpensive while also being safer for civil engineering infrastructure. A complete study on high-strength concrete made with sawdust ash and durability difficulties, in particular, has not been done, according to a review of the literature on sawdust ash that spans from the early days to the present. Therefore, it is important to consider this for next research. Research and construction interests are expected to be piqued by new ecologically friendly and energy-efficient construction composites such those made of bitumen-sawdust admixtures, polymer-sawdust admixtures, and cement-sawdust admixtures. Future construction projects might possibly use sawdust composites as lightweight roofing tiles and construction formwork.

6.3 Established gaps in literature

The utilization of sawdust composite in construction has a positive impact on the environment as it utilizes a byproduct that would otherwise go to waste. However, while significant progress has been made, there are still some gaps in the literature that need to be addressed. some potential gaps in the reviewed literature are listed below:

Table 7 Summary of comparison between the current and existing works

References	Parameters considered in research gap					
	SSCM	LDS	FR	HS	CE	SP
[58]	√	√		√		√
[60]	√	√			√	√
[61]	√			√	√	
[63]	√		√			√
[79]	√	√			√	√
[86]	√			√	√	√
[102]	√		√		√	√
[109]	√					√
[135]	√				√	√
[136]	√	√			√	
[137]		√	√		√	
[138]			√		√	

SSCM standardization of sawdust as a construction material; *LDS* long-term durability and stability; *FR* fire resistance; *HS* health and safety; *CE* cost-effectiveness; *SP* structural performance

6.3.1 Standardization of sawdust as a construction material

Currently, there are no clear standards for using sawdust as a construction material. This lack of standardization makes it difficult to compare the performance of sawdust-based products to traditional building materials.

6.3.2 Long-term durability and stability

While sawdust has been used as a building material in certain applications, its long-term durability and stability have not been extensively researched. This is particularly important in regions with high humidity or rainfall, where moisture can damage or degrade the sawdust.

6.3.3 Fire resistance

Sawdust is a combustible material, and its fire resistance is yet to be well studied. This is an important consideration for building codes and safety regulations.

6.3.4 Health and safety

Sawdust can pose a health hazard if inhaled, and there is limited research on the potential health effects of using sawdust as a construction material. This is particularly important for workers who handle and install sawdust-based products.

6.3.5 Cost-effectiveness

While sawdust is a renewable and low-cost material, its cost-effectiveness as a construction material has not been extensively studied. This is particularly important when considering the long-term costs of maintenance and repair.

6.3.6 Structural performance

Sawdust-based products have not been widely tested for their structural performance, which is important for ensuring safety and reliability of buildings constructed with this material.

Overall, there is still much to be learned about sawdust utilization, and continued research is needed to address these gaps in the literature. Addressing these research gaps will be critical to establishing sawdust as a viable and sustainable construction material.

Table 7 shows the assessment of some essential factors from relevant literature works on the application of sawdust in the development of sustainable composite materials for construction purposes. This will help to identify gaps, limitations, and areas to improve from existing literatures. Factors such as standardization of sawdust as a construction material, cost effectiveness, and structural performance were analysed in most of the research works considered, while limited studies were carried out on long-term durability and stability, fire resistance, health and safety factors.

7 Conclusion

Sawdust composite is an eco-friendly and sustainable material that has the potential to be used in various construction applications. It is a composite material made by mixing sawdust with a binding agent, such as resin or cement. One of the main advantages of using sawdust composite in construction is its low cost and abundant availability. Sawdust is a by-product of various wood industries, and its utilization in composite material production can reduce waste and lower costs.

The study shows that it is feasible to create good lightweight structural concrete by substituting sawdust for the typical quantity of sand and also sawdust ash for cement in a concrete mixture by adding between 5% and 15%. Sawdust concrete loses strength dramatically at ratios of sawdust and sawdust ash higher than this. It is also possible to produce sawdust bricks and blocks with compressive and water absorption qualities that meet international standards by substituting 10–30% of the sand used in the production of blocks and bricks with sawdust. Sawdust composite also has good thermal and acoustic insulation properties, making it suitable for use in walls, roofs, and floors.

Frequent use of sawdust by the construction industry will considerably aid in the creation and usage of environmentally friendly and sustainable building materials. In addition, the use of sawdust for construction purpose will minimize CO_2 emissions that is connected with the use of natural building materials, save energy, and help to preserve non-renewable building resources. Therefore, developing nations should view sawdust as a potential byproduct useful in the construction industry, as opposed to viewing it as waste.

However, sawdust composite may have some limitations, such as low resistance to moisture and fire. Therefore, appropriate measures need to be taken to enhance its resistance to these factors.

Overall, the utilization of sawdust composite in construction can provide a sustainable and cost-effective solution while also addressing environmental concerns. Further research and development are necessary to improve its properties and enhance its performance in construction applications.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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