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Review Article

A Review of Non-wood Lignocellulose Waste Material Reinforced Concrete for Light-weight Construction Applications

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ABSTRACT

In recent decades, non-wood lignocellulosic materials have gained significant attention, particularly in concrete applications for construction purposes. This study delves into utilising non-wood lignocellulosic materials for reinforcing concrete in construction applications. Lignocellulosic material emerges as a promising option for formulating new fibre cement compositions, thereby enhancing the sustainability, affordability, and performance of construction materials. Moreover, this research broadens the horizons of recycling agricultural waste by facilitating rational disposal and optimal utilisation. Through a comprehensive review, the study reveals that flax fibres, coir pith, prickly pear fibres, and rice husk ash waste exhibit superior workability compared to their counterparts. Furthermore, the strength of non-wood lignocellulosic reinforced concrete, incorporating bagasse ash, rice husk ash, and nutshell ash, peaked when fine aggregate replacement reached 15%, surpassing other types of non-wood

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lignocellulosic reinforced concrete. Adding a small quantity of prickly pear fibre to cement enhances the thermal conductivity of concrete, consequently improving compressive strength, flexural strength, tensile strength, and elastic modulus. This research is relevant to international research as it advances sustainable construction materials with desirable properties, benefiting society and various industries.

Keywords: Impact, light-weight construction, mechanical properties, non-wood lignocellulose waste, reinforced-concrete

INTRODUCTION

Lignocellulosic materials, derived from crop residues, are vital resources comprising lignin, cellulose, and hemicellulose. They fall into two categories: wood and non-wood. Wood includes hardwood and softwood (Feen et al., 2017; Radzi et al., 2019), while non-wood encompasses materials like sugarcane bagasse (Monteiro et al., 2019), rice husks (Yang et al., 2006), and pineapple leaves (Najeeb et al., 2021). Non-wood resources are gaining prominence due to tree scarcity and global fibre demand. They offer advantages like easier processing and shorter growth cycles. Non-wood lignocellulosic materials find applications across diverse fields, from pulp and paper to bioenergy and construction materials. Increasing demand for construction materials, the depletion of fossil fuels, and environmental concerns pose challenges (Gregorova et al., 2011; Supian et al., 2018; Thiruganasambanthan et al., 2022).

Several factors affect the demand for lignocellulosic materials. The depletion of fossil fuel resources, raw material shortages, increased demand for building materials, and emerging environmental issues such as pollution and global warming pose significant challenges to the construction industry. In the context of concrete, lignocellulosic materials are utilised as substitutes for cement, aiming to address the environmental impact of the cement industry, which accounts for a substantial portion of worldwide CO^2 emissions (Ali et al., 2020, 2021; Syamsir et al., 2023; Zeidabadi et al., 2018). The use of agricultural waste materials as concrete aggregates has been identified as a viable approach to reducing raw material consumption. Developing nations generate approximately 400 million metric tonnes of agricultural waste annually, and the adoption of waste materials in concrete production could contribute to a more sustainable building sector (Bakar & Chin, 2021; Kadier et al., 2021; Omran et al., 2021; Pil et al., 2016). The manufacturing process of Portland cement, as well as the energy, water, aggregate, and fillers required for concrete production and the subsequent disposal of concrete waste, raise concerns regarding the ecological criteria of the contemporary sustainable building sector.

Over the past four decades, extensive research has focused on non-wood lignocellulosic-reinforced concrete composites, aiming to create cost-effective innovations (Hamid et al., 2022; Lima et al., 2013; Momoh & Osofero, 2019; Singh et al., 2021). These studies consistently show that when lignocellulosic materials are added to cement, it boosts tensile strength and lowers density, enabling applications like fire resistance, thermal insulation, and acoustics. They can replace asbestos-cement and reconstituted wood products such as plywood and particleboard. A significant study by Momoh and Osofero (2019) specifically investigated using oil palm fibres in reinforced concrete. This study highlighted the growing global concerns about carbon emissions in the construction industry. As construction activities contribute significantly to yearly CO_2 emissions and resource use, it is essential to explore sustainable alternatives. With the world's population expected to increase by a third by 2050, agricultural operations and the generation of agricultural waste will rise, especially in emerging nations. It emphasises the need for sustainable construction practices.

Therefore, this study review has been conducted with a comprehensive review of academic literature to provide an overview of how agricultural waste can be used in the concrete industry. Specifically, this study investigates how different agricultural waste materials can replace some of the cement or aggregate in concrete, affecting its properties in various ways. After analysing existing research, this paper identifies the most suitable types of agricultural waste for concrete applications and discusses their broader implications. It includes their positive environmental impact and how they can efficiently utilise agricultural waste. Therefore, this review highlights the importance of agricultural waste research for the concrete industry, contributing valuable insights to the global research community.

AGRICULTURE WASTE

Recent developments in the management and utilisation of agricultural waste signify a paradigm shift in the perception of these materials, which were once considered mere by-products or residues. This critical review assesses these recent advancements and highlights their potential benefits and applications across various sectors. Agricultural waste encompasses a wide array of materials, including crop residues, weeds, leaf litter, sawdust, forest waste, and livestock waste. These materials are generated while cultivating and utilising various agricultural products, such as maise, nutmeg, sugar cane, wood, and palm oil. Recognising and categorising these waste streams is a crucial step in harnessing their potential (Alhazmi & Loy, 2021; Athira et al., 2019; Drück et al., 2020; Hulle et al., 2015; Jain et al., 2015; Lee et al., 2009; Li et al., 2014; Manickam et al., 2015; Pinto et al., 2012; Reddy & Santhosha, 2018).

Recent research has transformed our vision of agricultural waste. These materials are no longer mere by-products but valuable resources that can be harnessed for various purposes. The shift in perception has led to re-evaluating their potential across diverse applications. It includes bioenergy production, composting to enhance soil health, and the development of sustainable construction materials and value-added products (Jha et al., 2021; Kumar et al., 2016; Momoh & Osofero, 2020; Shafigh et al., 2014). Several factors drive the growing interest in agricultural waste management and utilisation. First, it aligns with sustainability goals by reducing waste and environmental impact. Second, it offers economic benefits by creating opportunities for generating income from waste streams. Additionally, it addresses pressing challenges, such as the need for alternative energy sources and sustainable construction materials in an era of environmental concerns and resource scarcity.

While recent developments are promising, challenges persist. These include logistical issues related to waste collection and processing, technological constraints in converting waste to valuable products, and the need for regulatory frameworks to govern waste utilisation. Future research should focus on optimising waste utilisation methods, exploring innovative applications, and addressing the environmental and social implications of these practices. Therefore, recent advancements in agricultural waste management and utilisation mark a significant shift towards recognising the value of these materials. Their multifaceted applications, ranging from energy production to sustainable construction, promise a more sustainable and resource-efficient future. However, addressing existing challenges and fostering interdisciplinary collaboration will be crucial to fully realising the potential of agricultural waste across various sectors.

Types of Crop Agricultural Waste

Numerous improvements have been made lately in agricultural waste, showing a wide range of options and advantages in numerous industries (Figure 1). The utilisation of various crop waste products is examined in depth in this critical assessment, which also discusses their economic and environmental significance. The landscape of agricultural waste is incredibly diverse, encompassing a wide range of materials. It includes rice paws, rice husk ash, bagasse ash, sugar cane fibres, flax fibres, ash waste, palm oil, nutshell ash, bamboo leaves, apricots, and numerous other agricultural residues (Asyraf et al., 2021; Kadier et al., 2021). These materials are generated globally in millions of metric tonnes each year, primarily consisting of plant stems, leaves, and mesocarp that remain after the main plant products are harvested (Jaafar et al., 2018; Kengkhetkit & Amornsakchai, 2012; Khan et al., 2010; Norrrahim et al., 2019; Saba et al., 2015; Sreekala et al., 1997).

The realisation of value-added opportunities linked with agricultural waste, particularly in rural regions, is a significant development in economic opportunities. These waste materials, often considered burdensome, can become valuable resources when properly harnessed. This shift can have substantial economic implications for industrial activities in rural regions (Azman et al., 2021; Nurazzi et al., 2021; Chavan et al., 2020). Figures 1 to 4 in this review visually represent some of the most prevalent types of agricultural waste discussed. This visual representation underscores these materials' sheer diversity and potential (Al-shayaa et al., 2021; Alhazmi & Loy, 2021; Heniegal et al., 2020). As this critical analysis emphasises, the optimal use of agricultural waste goes well beyond waste reduction, moving towards

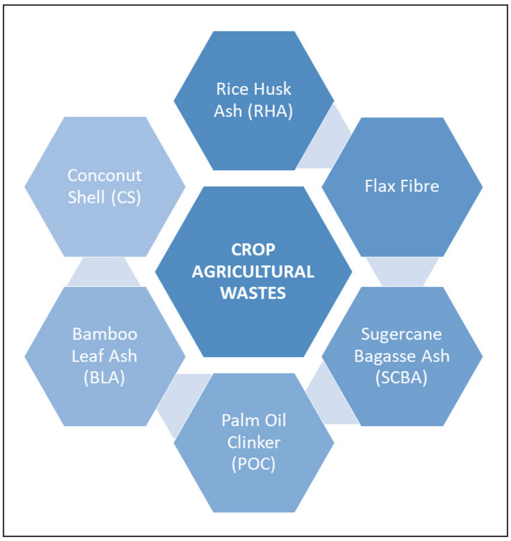

Figure 1. Classification of lignocellulose material from crop agricultural wastes used in the industry of concrete from other studies (Foo & Hameed, 2009; Susilawati et al., 2020)

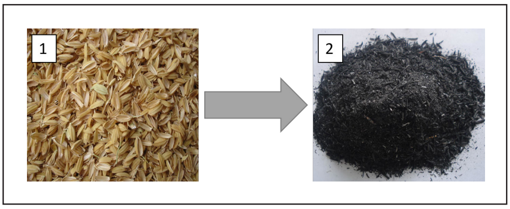

Figure 2. Examples of agro-waste: (1) Rice husk. (2) Rice husk ash (Mohamad et al., 2019)

Figure 3. Examples of agro-waste: (1) Sugarcane bagasse. (2) Sugarcane bagasse ash (Mohamad et al., 2019)

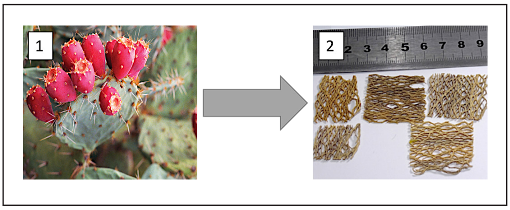

Figure 4. Examples of agro-waste: (1) Prickly pear. (2) Prickly pear fibres (Kammoun & Trabelsi, 2019)

sustainability and economic practices. It offers a pathway to sustainable and economically sound practices. Converting these waste materials into valuable products, such as bioenergy, construction, and value-added products, reduces environmental burdens and contributes to economic growth.

While the potential is evident, challenges remain. These include technological and logistical hurdles in converting waste to valuable products, as well as the need for supportive policies and practices. Future developments should focus on optimising utilisation methods, exploring innovative applications, and addressing sustainability concerns. Thus, recent developments in agricultural waste utilisation emphasise the vast potential of these materials. From waste reduction to economic growth and sustainability, the proper management and utilisation of agricultural waste can revolutionise various industries. As research and practices evolve, the world is poised to unlock new possibilities for harnessing these resources, fostering economic and environmental prosperity.

The Importance of Using Agricultural Waste in Concrete

Recent developments in the utilisation of agricultural waste in concrete construction have sparked significant advancements in the housing and infrastructure sectors, offering promising long-term benefits, cost-effectiveness, and environmental sustainability compared to conventional Portland cement (El-Messiry et al., 2017; Libre et al., 2011). The increasing interest among researchers and builders in utilising agro-residuals in concrete is driven by their potential to revolutionise the construction industry and improve nationwide infrastructure. This approach aligns with expanding socio-economic conditions and engineering innovations (Alsubari et al., 2021; Sizirici et al., 2021). Crop wastes, which make up a substantial portion of global agricultural biomass, have gained prominence due to their abundance and cost-effectiveness, making them a viable choice for sustainable construction practices. Agricultural waste products contain fibres with valuable characteristics, including stiffness, high efficacy, thermal insulation, and tensile properties. These fibres contribute to the overall performance of agro-cement composites, enhancing their suitability for various construction applications. Agro-cement composites demonstrate exceptional heat insulation capabilities. This feature addresses the challenge of agricultural waste disposal and contributes to mitigating the urban heat island effect. It aligns with sustainable urban development goals by creating more comfortable and energy-efficient living environments.

Using agricultural waste in concrete reduces waste and disposal issues and the carbon footprint associated with traditional cement production. This eco-friendly approach supports environmental conservation and sustainability goals. Additionally, it offers economic benefits through cost savings and potentially opens up new revenue streams for farmers and agricultural industries. Furthermore, recent developments in integrating agricultural waste into concrete have unveiled a sustainable and efficient approach with multiple advantages. These include waste reduction, cost-effectiveness, enhanced material properties, and environmental friendliness. This innovation holds the potential to transform the construction industry and improve the quality of infrastructure while promoting environmental responsibility. However, challenges remain, including optimising processing methods, ensuring product consistency, and addressing regulatory considerations. Future research and development efforts should focus on overcoming these challenges to fully harness the potential of agro-cement composites.

FRESH CONCRETE PROPERTIES

Workability

The workability of such compositions, essential for their practical application in construction, is vital information gained from carefully examining recent developments in using agro-waste materials in concrete mixtures. Workability is a key consideration when incorporating agro-waste materials into concrete, and researchers have extensively investigated this aspect. Slump tests have been widely conducted to evaluate the workability of various concrete mixtures (Givi et al., 2010; Oorkalan & Chithra, 2020). Researchers have found that the choice of agro-waste material significantly influences workability. For instance, rice husk ash has been associated with a high slump value, indicating good workability. On the other hand, when used as a partial substitute for fine aggregate, coconut coir pith resulted in a lower slump value, suggesting reduced workability. Several factors contribute to variations in workability. The inclusion of certain agro-waste materials, such as oil palm broom fibre (OPBF), red mud (RM), and fine palm oil clinker (POC) aggregate, can decrease workability. The reduction in workability with fine POC is attributed to fewer voids compared to aggregate size, reducing the need for additional lubrication (Abutaha et al., 2016). Similarly, RM's weight and fine particle size lead to increased water absorption and reduced flow.

The impact of agro-waste fibres on workability varies. For instance, prickly pear fibres have minimal effects on workability, with only a slight decrease in slump value observed for longer fibres. Longer fibres can sometimes cause segregation during concrete mixing (Kammoun & Trabelsi, 2019). Moreover, the presence of specific agro-waste materials can influence the water-to-binder ratio. Rice husk ash allows for a lower water-to-binder ratio while maintaining the required workability. In contrast, samples containing processed waste tea ash (PWTA) require an increased water-to-binder ratio due to its porous nature and high specific surface area, leading to water absorption during mixing (Djamaluddin et al., 2020). Different agro-waste materials exhibit unique characteristics that impact workability. For example, concrete mixes containing blast furnace slag (BLA) require more water than powdered clay brick mixes to achieve a comparable slump (Kolawole et al., 2021).

The increased workability of the coir pith (CP) can be attributed to its substantial water absorption capacity (Oorkalan & Chithra, 2020). Even short-length fibres in materials like prickly pear fibres (PPF) and flax fibres (FF) can significantly affect workability. Figure 5 illustrates the influence of various agro-waste materials on concrete workability. It provides

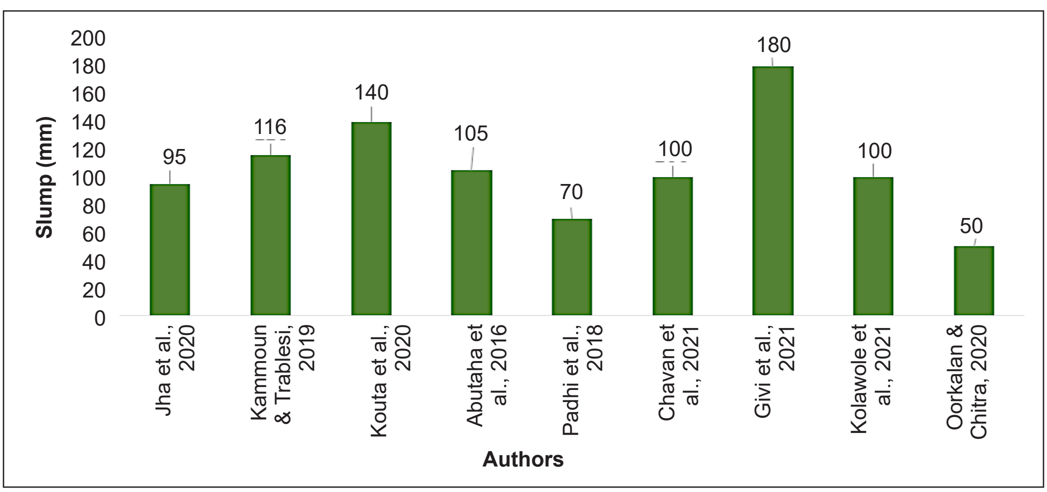

Figure 5. Maximum slump result from different studies

valuable insights into their effects on the water-to-binder ratio, water absorption, and slump values. These findings contribute to optimising concrete mixtures and effectively utilising agro-waste materials in construction applications. In outcome, successful agro-waste integration into construction practice depends on understanding how various agro-waste elements affect the workability of concrete mixtures. To create sustainable and successful concrete formulations, researchers have discovered critical elements and traits that affect workability.

Bulk Density

A thorough analysis of recent advancements in the field reveals a variety of findings regarding the bulk density of concrete containing various types of agro-waste materials (Ogundipe et al., 2021; Wu et al., 2018). Figure 6 compares the maximum bulk density values reported in various studies. Ogundipe et al. (2021) recorded the highest value of 2500 kg/m^3 when using Periwinkle (PWS) and Palm Kernel Shells (PKS) as agricultural waste in their study. On the other hand, Wu et al. (2018) reported the lowest value of 575 kg/m^3 when utilising carbonised apricot shell (CAS) as a substitute for coarse aggregate in the concrete mix. Figure 6 also presents the bulk density values of other agro-waste materials, such as Corn Cob Ash (CCA), Palm Oil Clinker (POC), Periwinkle (PWS), Palm Kernel Shells (PKS), Processed Waste Tea Ash (PWTA), Rice Husk Ash (RHA), and Bagasse Ash (BA). The use of carbonised materials resulted in reduced concrete density and specific density. The concrete density of peach shell (PS) was lower than that of apricot shell (AS) due to the lighter nature of peach shells.

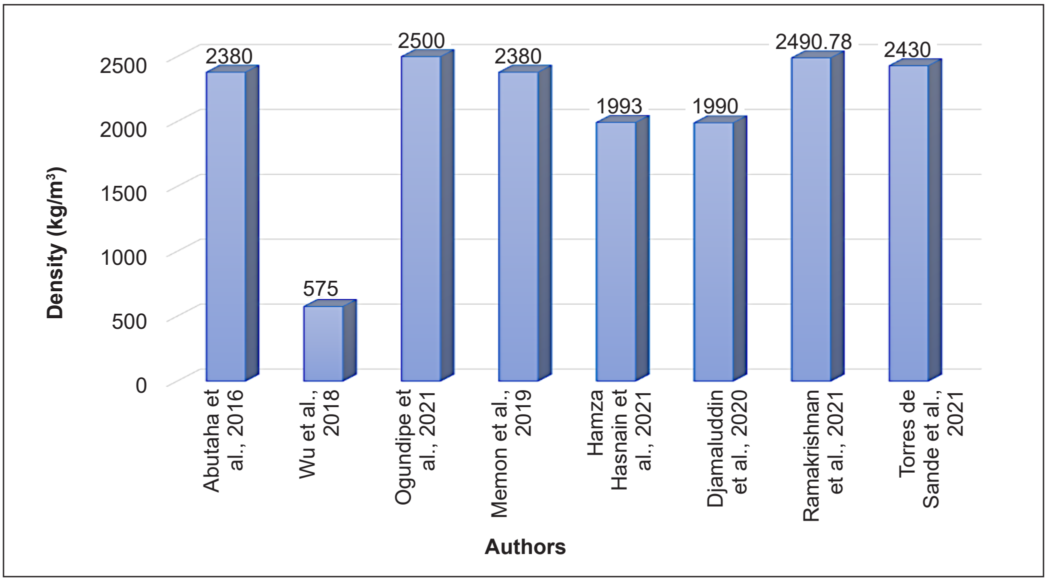

Figure 6. Maximum bulk density results from different studies

The reduction in bulk density observed in the Memon et al. (2019) study with corncob ash (CCA) was attributed to its lower density compared to fine aggregates (Memon et al., 2019). Similarly, the reduction in density with PWTA was due to its lower density, which also affected the overall density of paving block concrete (Djamaluddin et al., 2020; de Sande et al., 2021). Furthermore, the study by de Sande et al. (2021) has indicated that when sugarcane bagasse ash (ScBA) was used as a substitute, the density values initially increased to an optimum replacement level of 15%. However, concentrations of ScBA exceeding 15% delayed the hydration process, leading to a decline in density. The finer particles of ScBA filled the voids in the concrete mass, resulting in an increased density of up to 15% replacement. Therefore, the thorough research emphasises how different agro-waste elements affect the bulk density of concrete. The results show how diverse waste kinds, including carbonised materials, the effect of ash content on hydration, and the connection between agro-ashes and overall concrete porosity affect density. These observations help us better understand how to optimise concrete mixtures for use in construction applications employing agro-waste components.

Shrinkage

The data presented in Figure 7 illustrates the range of shrinkage values obtained from various studies, where most agro-waste materials contribute to a decrease in shrinkage (Kouta et al., 2020; Shaaban, 2021). The study by Kouta et al. (2020) reported a maximum shrinkage value of 3,520 macrostrain when utilising flax fibre. Conversely, Shaaban (2021) discovered that the combination of rice husk ash and calcined dolomite powder resulted in the lowest shrinkage value of 60 macrostrains. Otherwise, the presence of specific additives such as alum sludge (AS), flax fibre (FF), carpet fibre (CF), and rice husk ash (RHA) leads to a reduction in shrinkage. For instance, increasing the content of alum sludge by 5% to 10% decreases shrinkage during drying and heating processes (Kaish et al., 2021). It can

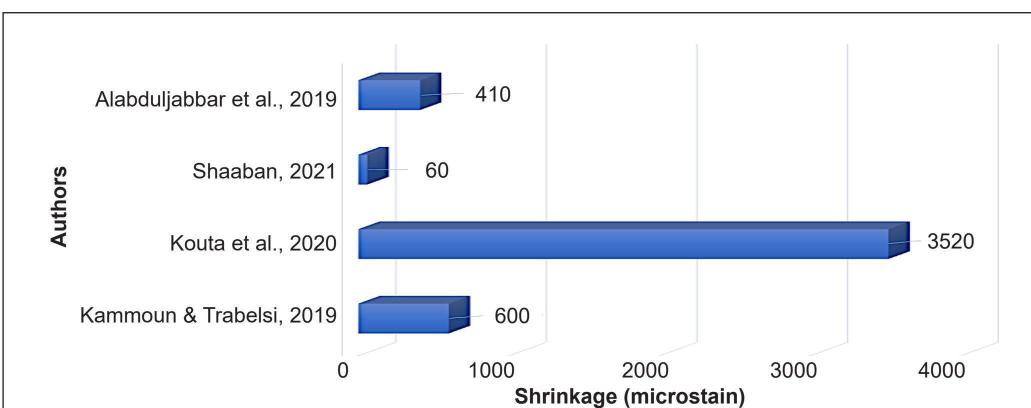

Figure 7. Maximum shrinkage results from different studies

be attributed to small granules of alum sludge within the concrete, which effectively fills capillary gaps and reduces water loss within the concrete structure.

Furthermore, Kouta et al. (2020) indicated that adding 0.3% and 0.6% flax fibres demonstrates a significant decrease in plastic shrinkage compared to the control sample. The length of the flax fibres plays a crucial role, with longer fibres exhibiting a greater impact on reducing the rate and magnitude of plastic shrinkage. This behaviour can be attributed to the increased surface area coverage of longer fibres, which enhances the bonding between concrete particles and mitigates shrinkage (Kaish et al., 2021; Kouta et al., 2020). The presence of additives like alum sludge and flax fibres demonstrates promising results in mitigating plastic and drying shrinkage. Further research and experimentation are warranted to optimise the proportions and combinations of agro-waste materials to achieve the desired reduction in shrinkage while maintaining the overall mechanical properties of the concrete. Overall, the studies reviewed indicate that incorporating certain agro-waste materials can effectively reduce shrinkage in concrete.

HARDENED CONCRETE PROPERTIES

Compressive Strength

Recent developments in using agro-waste materials in concrete have shed light on their impact on compressive strength. Figure 8 provides a comparative analysis of maximum compressive strength values reported in various studies, revealing valuable insights. The data indicates a wide range of compressive strength values achieved through different agro-waste materials. The highest compressive strength, reaching 50.67 MPa, was observed in a

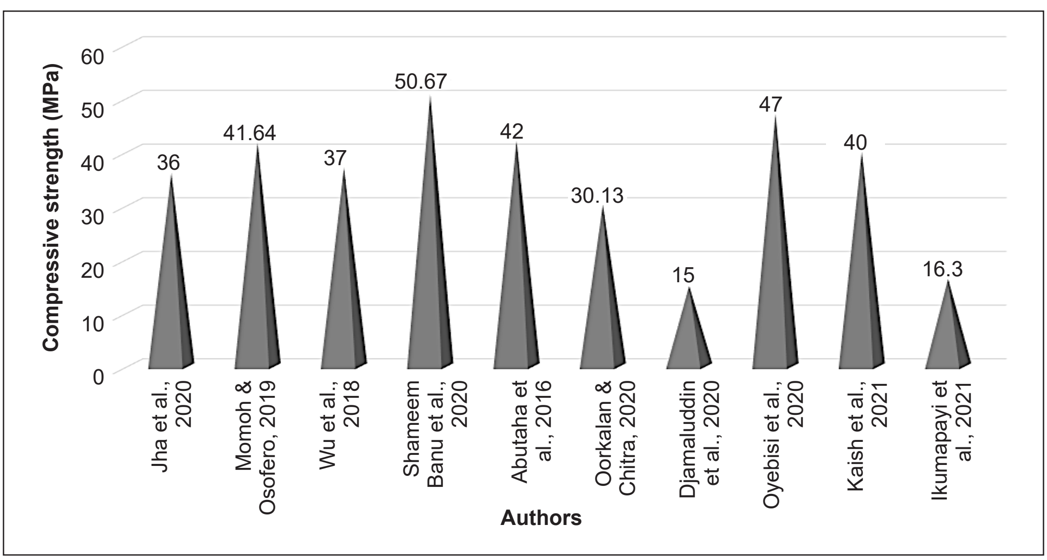

Figure 8. Maximum compressive strength results after 28 days from different studies

study using rice husk ash (RHA) conducted by Banu et al. (2020). Conversely, the lowest compressive strength, 15 MPa, was reported in a study utilising processed waste tea ash (PWTA) by Djamaluddin et al. (2020). It is noteworthy that the inclusion of PWTA and oil palm broom fibres (OPBF) has been found to decrease compressive strength, as reported in studies by Djamaluddin et al. (2020) and Momoh and Dahunsi (2017). In contrast, the compressive strength was observed to increase with the addition of alum sludge (AS), rice husk ash (RHA), and carbonised apricot shell (CAS) (Djamaluddin et al., 2020; Momoh & Dahunsi, 2017; Banu et al., 2020).

Some agro-waste replacements reached their maximum compressive strength at relatively low substitution percentages. For instance, groundnut shell ash (GSA), coconut coir pith (CCP), sugarcane bagasse ash (ScBA), and Anacardium occidentale nutshell ash (AONSA) achieved their peak compressive strengths at modest substitution levels (Djamaluddin et al., 2020; Ikumapayi et al., 2021; Jha et al., 2021; Momoh & Dahunsi, 2017; Oorkalan & Chithra, 2020; Oyebisi et al., 2020; Banu et al., 2020). Otherwise, the study by Ikumapayi et al. (2021) revealed that the highest compressive strength with groundnut shell ash (GSA) was achieved at an 8% ordinary Portland cement (OPC) substitution, with a subsequent decline in strength at higher substitution percentages. Its decrease in strength is attributed to the higher hydration response of 8% GSA.

The water absorption characteristics of agro-waste materials, such as coir pith, also affect compressive strength. The study by Oorkalan and Chithra (2020) demonstrated a steady loss of strength when the coir pith was replaced by more than 5% in the concrete mix due to the absorbed water content of the coir pith. Agro-waste materials like sugarcane bagasse ash (ScBA) exhibited increased compressive strength due to their pozzolanic characteristics and unique physical and chemical properties. Furthermore, carbonised apricot shell (CAS) showed improved compressive strength, attributed to enhanced bonding between mortar and raw aggregates. The carbonisation process results in a rougher surface and improved interlocking of concrete particles (Kaish et al., 2021; Wu et al., 2018). The variations in compressive strength observed with different agro-waste materials highlight the importance of considering the type and proportion of agro-waste, as well as curing conditions. Achieving desired compressive strength levels while maintaining concrete quality and durability requires further research and the establishment of standardised guidelines for agro-waste incorporation in concrete.

Therefore, recent developments emphasise the potential for agro-waste materials to impact concrete compressive strength positively (Abutaha et al., 2016; Djamaluddin et al., 2020; Momoh & Osofero, 2019; Banu et al., 2020). However, the influence of specific agro-waste types, proportions, and curing conditions must be carefully considered to optimise concrete formulations effectively. Further research is essential to refine practices and ensure consistent results while utilising these sustainable materials in construction.

Flexural Strength

A comprehensive analysis of recent developments in flexural strength, considering various materials as additives in concrete, reveals intriguing findings. Thus, numerous studies indicate that the inclusion of certain materials in concrete can either enhance or weaken its flexural strength. For instance, carpet fibre (CF), prickly pear fibre (PPF), and rice husk ash (RHA) have been found to boost flexural strength. Conversely, when sugar cane bagasse ash (ScBA) and processed waste tea ash (PWTA) are incorporated, flexural strength tends to weaken (Alabduljabbar et al., 2021; Djamaluddin et al., 2020; Kaish et al., 2021; Oorkalan & Chithra, 2020; Gar et al., 2017; Shaaban, 2021). Figure 9 showcases the highest flexural strength value of 7.4 MPa reported in Shaaban's (2021) study using rice husk ash (RHA). In contrast, the lowest flexural strength of 1.53 MPa was observed in a Gar et al. (2017) study using sugarcane bagasse ash (ScBA).

Otherwise, the alum sludge (AS) demonstrated a slight increase in flexural strength, up to 10% fine aggregate replacement, as reported by Kaish et al. (2021). However, flexural strength declined with a 15% AS replacement. Meanwhile, the flexural strength of concrete mixes with 5% coir pith (CP), according to Oorkalan and Chithra's (2020) study, remained relatively consistent initially but decreased after 28 days of curing.

Furthermore, Momoh and Osofero's (2019) study found that flexural strength initially increased with adding oil palm broom fibres (OPBF) by up to 3%; however, it decreased when the percentage of OPBF exceeded 3%. The weak radial strength of OPBF and insufficient fibre-to-concrete matrix bonding may explain the lack of significant gains in flexural strength.

Meanwhile, Alabduljabbar et al. (2021) proposed that the improved flexural performance of concrete, especially with carpet fibres, may result from the bridging

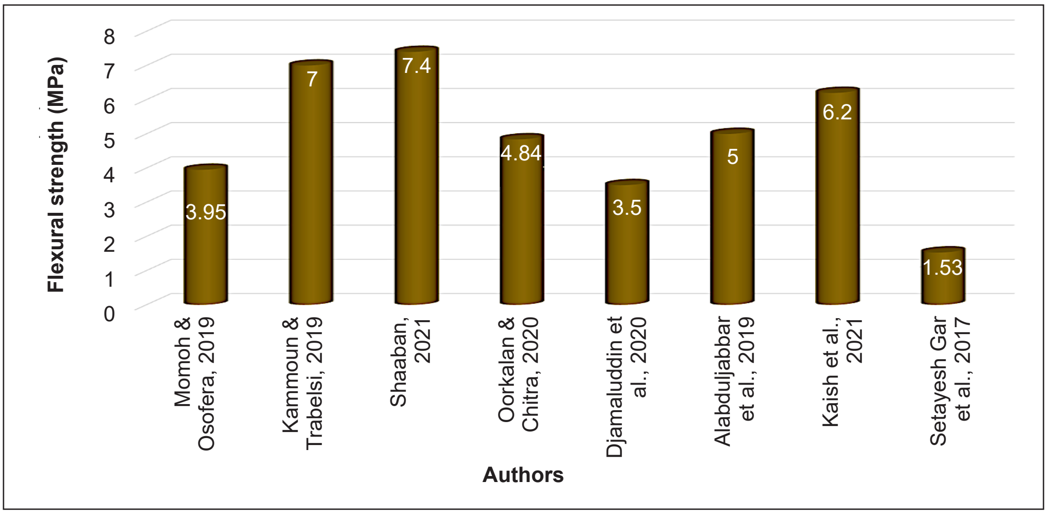

Figure 9. Maximum flexural strength results after 28 days from different studies

effect of these fibres. This effect enables fibres to transmit stress across cracks, enhancing flexural strength. Gar et al. (2017) observed that concrete compositions containing 5% coir pith (CP) exhibited better flexural strength, regardless of curing methods. However, when the temperature exceeded 300°C, samples containing sugarcane bagasse ash (ScBA) experienced a noticeable decrease in residual flexural strength. Shaaban (2021) explained that the increase in flexural strength with RHA can be attributed to a growth in possible flexural failure modes with increasing fault density. Excess unreacted RHA after CaO-MgO depletion contributes to this rise in flexural strength.

Therefore, these results highlight the complex link between different additives and how they affect the flexural strength of concrete. Understanding the mechanisms underlying these effects is crucial to optimise concrete compositions and achieve the required flexural strength while considering parameters such as material kind, proportion, and curing conditions. More study is required to establish standard practices and recommendations for these materials to be used efficiently in construction applications.

Modulus of Elasticity

Insights of note can be obtained from a thorough examination of recent advancements in the context of the modulus of elasticity in concrete, taking into consideration a variety of additives (Ahsan & Hossain, 2018; Islam et al., 2016; Kammoun & Trabelsi, 2019; Wu et al., 2018). Various studies have explored the effects of different additives on concrete's modulus of elasticity. Figure 10 illustrates the highest modulus of elasticity value, reaching 33.8 GPa, as reported by Kammoun and Trabelsi (2019), who utilised prickly pear fibre (PPF). Conversely, the lowest modulus of elasticity, 14 GPa, was observed in the study by Islam et al. (2016) when incorporating palm oil fuel ash (POFA).

Meanwhile, Kammoun and Trabelsi (2019) proposed that the addition of carbonised apricot shell (CAS) and rice husk ash (RHA) tends to increase the modulus of elasticity,

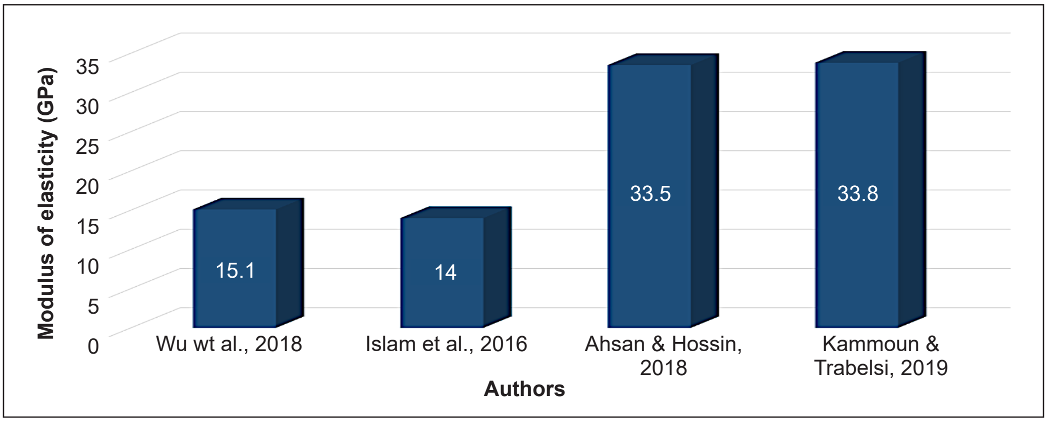

Figure 10. Maximum modulus of elasticity result from different studies

while it decreases with the addition of palm oil fuel ash (POFA) and prickly pear fibre (PPF). Furthermore, the inclusion of prickly pear fibres in concrete, particularly at a content of 15 kg/m^3, led to a substantial 40% reduction in the modulus of elasticity. Wu et al.'s (2018) study indicates that the modulus of elasticity increases by approximately 42.5% using a carbonised apricot shell (CAS). This improvement is attributed to enhanced binding capabilities at the aggregate-mortar interface when employing carbonised aggregates (Kammoun & Trabelsi, 2019; Wu et al., 2018). Meanwhile, the decrease in modulus of elasticity observed with rice husk ash (RHA) suggests lower concrete quality and reduced particle density. Additionally, using finer RHA reduced Poisson's ratio, indicating changes in lateral strain response to axial stress (Ahsan & Hossain, 2018). Interestingly, the length of prickly pear fibre (PPF) was not found to have any significant effect on the modulus of elasticity. Thus, this discussion provides valuable insights into how different additives impact the modulus of elasticity in concrete. It highlights the importance of understanding these additive effects on the elastic properties of concrete, which is crucial for optimising concrete mixtures and ensuring the desired performance characteristics. Further research is needed to explore these relationships in greater detail and develop guidelines for effectively incorporating additives in concrete mixtures.

Splitting Tensile Strength

A thorough investigation of recent improvements in splitting tensile strength (STS) in concrete, considering various additives, yields significant insights. Figure 11 illustrates the reported splitting tensile strength values from various studies, shedding light on concrete performance (Jha et al., 2021; Ramakrishnan et al., 2021; Selvasofia et al., 2021). Ramakrishnan et al. (2021) achieved a notably high splitting tensile strength of 6.74 MPa

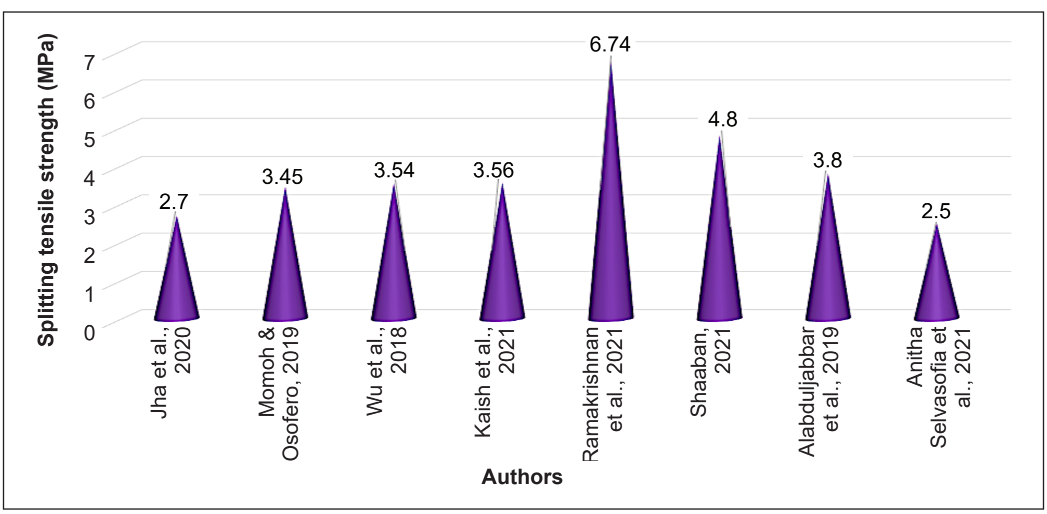

Figure 11. Maximum splitting tensile strength results after 28 days from different studies

using sugarcane bagasse ash. Conversely, Anitha et al. (2020) reported a lower value of 2.5 MPa when waste marble powder (WMP) was incorporated. The incorporation of WMP resulted in a 10% increase in splitting tensile strength, attributed to the finer size and angular shape of WMP particles. This characteristic enhances the concrete's performance. The study by Jha et al. (2021) observed an increase in splitting tensile strength with the addition of alum sludge (AS), carbonised apricot shell (CAS), and carpet fibre (CF), which has positively influenced STS.

However, incorporating oil palm broom fibres (OPBF) decreased splitting tensile strength. This reduction can be attributed to the agglomeration of OPBF at the top of the samples during the splitting tensile test, resulting in biaxial compression zones beneath the packing strips (Momoh & Osofero, 2019; Wu et al., 2018). Furthermore, Wu et al. (2018) reported improved STS with CAS. This enhancement is attributed to the rough concave surface of CAS particles, which are free of biological materials.

The evaluated research provides insightful information about the variables affecting concrete's splitting tensile strength. Besides, the additives, including carpet fibre (CF), waste marble powder (WMP), alum sludge (AS), carbonised apricot shell (CAS), and sugarcane bagasse ash can have a good effect on STS. However, due to agglomeration effects, adding oil palm broom fibres (OPBF) may cause a reduction in tensile strength (Wu et al., 2018). These results emphasise the importance of choosing the right additives to enhance concrete performance and guarantee optimum tensile strength characteristics.

THERMAL CONCRETE PROPERTIES

An in-depth analysis and critical examination of current advancements in the context of thermal conductivity in concrete, taking into consideration a variety of additives, provides significant insights, including the subsequent discussion (Kammoun & Trabelsi, 2019; Katare & Madurwar, 2021). Figure 12 presents a comparison of thermal conductivity results from various studies, offering valuable insights into the thermal properties of concrete. Kammoun and Trabelsi (2019) reported a relatively high thermal conductivity of 1.59 watts/mK when using prickly pear fibre (PPF). Conversely, Katare and Madurwar (2021) found a lower thermal conductivity value of 1.38 Watt/mK when incorporating sugarcane bagasse ash (ScBA).

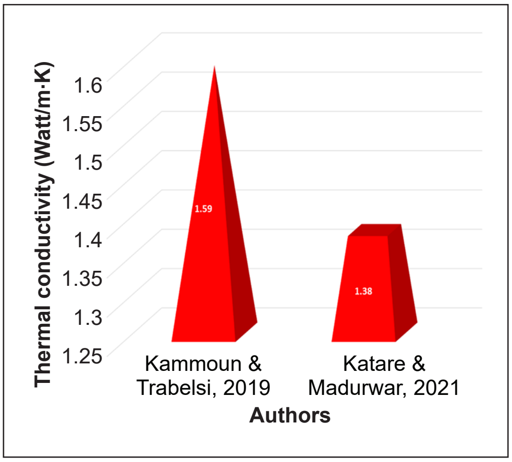

Figure 12. Maximum thermal conductivity results from different studies

Furthermore, the increase in the amount of sugarcane bagasse ash (ScBA) and prickly pear fibre (PPF) led to a decrease in the thermal conductivity of concrete. Katare and Madurwar's study demonstrated that higher percentages of ScBA resulted in lower densities and reduced thermal conductivity (2021). This reduction in density can be attributed to increased porosity and air-filled voids in the concrete, which lower the gas thermal capacity compared to the solid thermal conductivity of typical concrete. Otherwise, the study by Kammoun and Trabelsi (2019) indicated that the inclusion of longer fibres in composites often reduces heat conductivity. It suggests that longer fibres, such as PPF, can act as thermal insulators and reduce heat transfer within the concrete.

As a result of their effects on density and porosity, additives like sugarcane bagasse ash (ScBA) and prickly pear fibre (PPF) can reduce thermal conductivity in concrete. Longer fibres may also improve the thermal insulation capabilities of concrete, making this a promising method for raising its thermal performance. These results highlight the possibility of modifying concrete compositions to get the desired thermal conductivity properties for a range of applications.

CONCLUSION

In conclusion, this study primarily focused on assessing the workability of agro-waste concrete, and several key implications have arisen from our findings. As the proportion of agricultural waste increases, concrete strength and workability tend to decrease, indicating a potential trade-off when using such materials as partial replacements for conventional aggregates or cementitious substances. Prickly pear fibre inclusion in concrete results in heightened shrinkage, accelerating the ageing and drying processes and potentially leading to cracking. Conversely, carbonised apricot shells and rice husk ash have showcased promising performance as alternatives for both coarse and fine aggregates, offering opportunities to enhance concrete strength, resilience, and sustainability. Additionally, significantly incorporating sugarcane bagasse ash, carpet fibres, and alum sludge bolsters concrete's tensile strength, enabling it to withstand greater tensile forces and resist cracking.

Therefore, this study review emphasises the importance of judiciously selecting and proportioning agricultural waste in concrete formulations to optimise performance while advancing sustainable construction practices. Moreover, these findings have significant implications for future research and practice in the construction industry, highlighting the need for precise selection and proportioning of agricultural waste materials to optimise concrete performance while minimising environmental impact and paving the way for more sustainable and resilient construction practices.

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