Utilizing Agricultural Wastes to Produce Bio-Green Concrete and Zero-Cement Particle Boards

Arman Hatami Shirkouh

A Thesis

in

The Department

of

Building, Civil, and Environmental Engineering

Presented in Partial Fulfillment of the Requirements

for the Degree of Master of Applied Science (Civil Engineering) at

Concordia University

Montreal, Quebec, Canada

November 2023

CONCORDIA UNIVERSITY
School of Graduate Studies

This is to certify this thesis prepared.

By: Arman Hatami Shirkouh

Entitled: Utilizing Agricultural Wastes to produce Bio-Green Concrete and Zero-cement Particle Boards

And submitted in partial fulfillment the requirements for the degree of

Master of Applied Science (Civil Engineering)

Complies with the regulation of the University and meets the acceptable standards with respect to originality and quality.

Signed by the final examining committee:

Chair Dr. Chunjian An

Examiner Dr. Biao Li

Supervisor Dr. Ahmed Soliman

Approved by Dr. Chunjian An, Graduate Program Director

November 2023 Dr. Mourad Debbabi, Dean of Faculty

ABSTRACT

UTILIZING AGRICULTURAL WASTES TO PRODUCE BIO-GREEN CONCRETE AND ZERO-CEMENT PARTICLE BOARDS

Arman Hatami Shirkouh

A growing number of building projects seek eco-friendly and sustainable materials to reduce their environmental impact. Incorporating agro-waste into concrete production is one promising strategy. Agro-waste is often considered a replacement of coarse and fine aggregate or fiber, is a rich source of renewable and biodegradable materials that can enhance the performance and reduce the environmental footprint of these construction components. In previous studies, rice husk, coconut coir, sugarcane bagasse, and a variety of agricultural residue materials were found to be suitable for incorporation into concrete. The availability and affordability of these materials make them attractive alternatives to traditional non-renewable resources. Moreover, it highlights the importance of using agro-waste for environmental reasons, such as reducing the carbon footprint of construction materials and reducing the need for landfill disposal. These practices align with the principles of a circular economy, promoting the responsible use of resources. A discussion is provided of the performance and properties of the materials produced, including their strength, durability, and insulation capabilities. Agro-waste can enhance these attributes and increase the applications of concrete tiles and particle boards, contributing to the creation of sustainable and energy-efficient buildings. Agro-waste can be utilized to manufacture concrete tiles and particle boards in an environmentally friendly manner. The purpose of this study is to provide a summary of the potential benefits of integrating agro-waste into sustainable practices while addressing the challenges and opportunities associated with this innovative approach. This paper presents findings that are intended to inspire further research and development in the field of green construction materials.

Keywords: Agro-waste, Sustainable materials, Environmental impact, Circular economy, Green construction

CO-AUTHORSHIP STATEMENT

Substantial parts of this thesis were either published in or submitted for publication to peer-reviewed technical journals and an international conference. All experimental work, data analysis, and writing of initial versions of all publications listed below were carried out by the candidate himself. The contribution of this research advisor and any other co-author; if applicable, consisted of either providing advice and/or helping in the development of the final versions of publications:

1. **A. Hatami Shirkouh**, A. Soliman, "Characterization of Concrete Tiles Incorporating Agro-Waste: An Eco-Friendly Approach to Sustainable Construction", Journal Paper, (Draft under review).
2. **A. Hatami Shirkouh**, A. Soliman, "Performance of Eco-Friendly Zero-Cement Particle Board under Harsh Environment", Applied Science Journal (MDPI), (Accepted).
3. **A. Hatami Shirkouh**, A. Soliman, "Investigation optimization of the percentage of agro-waste in non-structure concrete", CSCE Annual Conference, 2023, (Accepted).
4. F. Meftahi, **A. Hatami Shirkouh**, k. Majumdar, R. Dhemaied, A. Soliman, "On the feasibility of producing cement-bonded particleboard panels containing agro-waste and silica fume", SHIMI-11, 2022, (Accepted).
5. O. Abdel Rahman, **A. Hatami Shirkouh**, A. Soliman, "Fresh and mechanical properties of sustainable SCM incorporating limestone filer as a replacement of cement", SHIMI-11, 2022, (Accepted).
6. **A. Hatami Shirkouh**, A. Soliman, "Application of agro-waste in the construction industry: a review", CSCE Annual Conference, 2022, (**published**).
7. **A. Hatami Shirkouh,** A. Soliman, "Rubberized alkali-activated concrete—a review", CSCE Annual Conference, 2021, (**Published**).

All authors reviewed the final manuscript and approved of the contents.

Acknowledgement

I would like to acknowledge and give my warmest thanks to my supervisor, Dr. Ahmed Soliman who made this work possible. His guidance and advice carried me through all the stages of writing my project. I would also like to thank my committee members for letting my defense be an enjoyable moment, and for your brilliant comments and suggestions, thanks to you.

I would also like to give special thanks to my family as a whole for their continuous support and understanding when undertaking my research and writing my project.

Finally, I would like to express my gratitude to all my friends and colleagues who have been a constant source of encouragement and motivation throughout this academic journey. Your unwavering support, insightful discussions, and shared experiences have truly enriched my research and made this endeavor all the more fulfilling.

In addition, I want to extend my thanks to the staff and resources at our institution, whose contributions and facilities have played an essential role in the successful completion of this project. Your commitment to fostering a conducive environment for research is deeply appreciated.

Table of Contents:

List of Figures:

List of Tables:

CHAPTER 1: Introduction

1.1 Background

The use of land in line with human development, which includes urbanization, transportation, settlements, etc., can significantly change the planet [1, 2]. Some of these damages and changes in the forest and agriculture area can be compensated if the activities are stopped and measurements are taken to restore and replant them [3]. On the other hand, the changes that have replaced the physical structure of the vegetation are unchangeable and considered permanent by many. In this regard, infrastructures made of metals and concrete have caused some permanent changes on the planet [4]. Today, there is increasing attention and interest to review the construction industry and how to use materials in a way that has minimal damage to the environment [5-7]. At the center of this review is the topic and discussion about concrete, which is a widely used construction material and has recently been described as the most destructive material on earth [8].

Concrete is considered one of the oldest building materials in the world. This valuable material has played a significant role in the development of modern society, which includes the construction of road networks, water supply systems, construction of buildings and structures, dams, bridges, and health infrastructure [9]. Steel, aluminum, and plastic are not the most popular synthetic materials in the world, but concrete tops the list [10-12]. After water, concrete is the most consumed material on the planet [13, 14].Concrete consists of 3 elements, which include 1) aggregate (such as gravel, sand, and crushed stone) 2) cement (usually Portland cement) and 3) water [15, 16]. When dry cement, aggregate, and water are combined, a fluid mixture is created that has the potential to be place in the framework.

Concrete, which is currently produced at a rate exceeding 10 billion tons per year, stands as the most crucial construction material. Forecasts indicate that the global population, currently ranging from 6 to 9 billion, will reach 11 billion by the close of this century. This population growth is expected to lead to a considerable rise in the need for resources such as water, energy, food, rivers, public goods, and services. This demographic expansion is also projected to boost the demand for concrete, potentially reaching approximately 18 billion tons annually by 2050. Consequently, the concrete industry will deplete a significant quantity of natural resources in the manufacturing of cement and concrete [17-19].

With the growth of the construction industry, there arose a heightened demand for improved concrete management. Amid various proposals, one prominent idea emerged: the development of an innovative and sustainable form of green concrete that preserves the strength and durability found in previous generations.

Green concrete is an environmentally conscious approach to concrete production and construction that prioritizes sustainability [20]. It incorporates several key strategies to minimize its impact on the environment. These strategies include using recycled materials like aggregates and even recycled concrete, which reduces the demand for new resources and limits waste. Green concrete often incorporates supplementary cementitious materials, such as fly ash or slag, which replace a portion of the Portland cement used in traditional concrete [21].

This reduction in cement content significantly reduces carbon dioxide (CO_2) emissions associated with cement production, a major contributor to the environmental footprint of concrete [22]. Additionally, green concrete may utilize energy-efficient production methods to further reduce its impact [23]. The use of green concrete has various positive effects. It contributes to a lower carbon footprint, which is crucial in combating climate change. Reduced water usage and efficient curing methods save water resources, especially in regions with water scarcity [24, 25]. Green concrete is often more durable, which means structures constructed with it require less maintenance and have a longer lifespan. Some formulations offer improved thermal insulation, helping reduce energy consumption for heating and cooling in buildings [26]. Overall, the adoption of green concrete aligns with sustainable building practices and environmental certification standards, promoting responsible and eco-friendly construction [27].

On the other hand, forecasts indicate the growth of agricultural production in the coming years. The purpose of these products is not only food for the human population but also part of industrial needs [28]. The increasing growth of bioenergy from biofuel has been an example of the diversification of agricultural products in recent years. This is more evident in products with starch and cellulose [29]. In addition, agricultural plant residues have a special place as biomass and are considered to have a good potential for green energy production [30]. In 2006, bioenergy accounted for about 10% of the world's energy [28]. The amount of demand for crops experienced a significant upward trend from 2000 to 2015 due to the topic of biofuel production [31].

1.2 Thesis Objective

The main goal of this thesis is to investigate the use of agro-waste in the production of cement-based concrete tile and alkali-activated particle board. Therefore, this study examines the physical and mechanical properties, durability performance of agro-waste concrete and optimizes the percentage of using agro-waste in production of concrete tile and particle board.

This objective will be achieved through the following stages:

1. Investigating the use of different percentages of agro-waste in the concrete and finding the optimization percent of agro-waste in production of concrete tile.
2. Evaluating the effect of agro-waste content in production of cement based concrete and concrete tile.
3. Evaluating the effect of agro-waste incorporating in zero-cement particle board under different curing conditions.
4. Developing a modified percentage of using agro-waste in the concrete industry that can be adapted to the concrete tile and particle board industries to improve the efficiency of production.

1.3 Structure of Thesis

This thesis has been prepared according to the guidelines of the Faculty of Graduate Studies at Concordia University. It comprises five chapters, two of which display the progress in the experimental program. Substantial parts of the thesis have been either published, accepted, or submitted for possible publication in peer-reviewed journals and national and international conferences.

Chapter two contains a state-of-the-art review of the current knowledge on the application of agro-waste in the concrete industry. Chapter three discusses the feasibility of using agro-waste concrete tile and the characterization of agro-waste concrete tile. Chapter four demonstrates the mechanical and durability of zero-cement particle board in different Curing Conditions. Finally, general and specific conclusions drawn from the research study, along with recommendations for future research, are included in chapter five.

1.4 Original Contributions

This research introduces a series of fundamental investigations related to agro-waste Specific original contributions of this dissertation include the following:

1. Developing an extensive database on the different types of agro-waste and their application in the building sector.
2. Investigate the effect of agro-waste in the various contents on the fresh, hardened properties and durability performance of the concrete industry.
3. Optimize the percentage of agro-waste in concrete and use applicable in the production of concrete tile.
4. Investigating the effects of agro-waste content on the physical and mechanical properties and durability performance in cement-based concrete and agro-waste concrete tile and zero-cement particle board.
5. Evaluating the effect of curing conditions and slag content in the production of the agro-waste zero cement particle board.
6. Identify the optimum ratio of agro-waste content in zero cement particle board to improve thermal properties.

CHAPTER 2: Literature Review

Protecting the environment has been one of modern human societies' main and most important concerns in the past few decades. The high demand for natural resources due to rapid urbanization and the problem of disposal of agricultural waste in different countries have created opportunities to use agricultural waste in the construction industry. The use of agricultural waste in concrete, in addition to reducing concrete costs and improving concrete properties, is done to reduce environmental pollution worldwide. The production and implementation of the green concrete plan are still in the initial stage. It seems that academicians and R&D should investigate green concrete more and contribute to developing it in the industry with more research. In this regard, studies have been conducted by various researchers around the world.

2.1 Introduction

Today, the modern construction industry faces many challenges due to two main reasons: decreasing natural resources and increasing the rate of urbanization. On the other hand, climate change has led the construction industry to consider using sustainable building materials. It should be pointed out that agricultural waste is a huge challenge for the agricultural industry, as waste such as rice husk, red gram crops, sugarcane, etc., are produced about 10 to 15 times more than other products. Therefore, to meet the demand of the construction industry for green building materials, agricultural waste seems to be a suitable option. ***Figure 2.1*** shows a summary of the benefits of environmentally friendly natural materials.

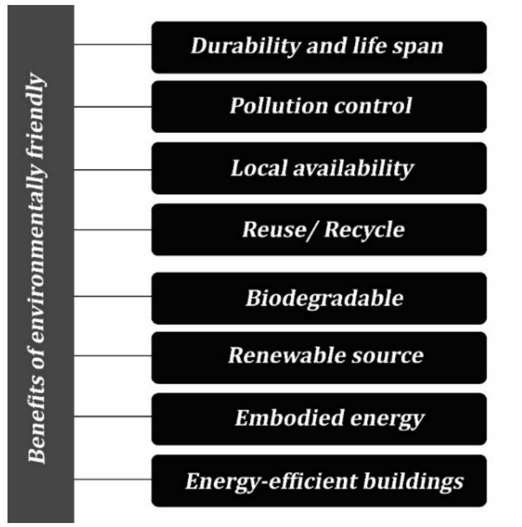


Figure 2.1: The benefits of environmentally friendly natural materials.

2.2 Recycled materials: an opportunity to compensate

According to the continuous concerns expressed by the United Nations and other responsible bodies about the change in the earth's ecology due to the damage caused by the construction industry, it seems that the desire of this industry to use recycled materials has increased in recent years. In this regard, in recent years, researchers have used various recycled materials in all types of concrete. **Heat *transfer*** and thermal insulation

Walls are an important part of structures. Walls generally play an important role in heat and cold inside the environment. One of the applications of agricultural products can be the use of these products for thermal insulation. Good thermal insulation can minimize the speed of heat transfer between two different environments. Plant waste derived from agricultural products are widely found all over the world. Among the important sources of these materials are the European Union, Russia, Belarus, Ukraine, Vietnam, Malaysia, India, and China. Wastes from these products are considered excellent resources for obtaining efficient aggregates for thermal insulation materials [32]. These wastes can be divided into two groups based on their structure [32]: Group 1, waste includes crushed stems or husks of agricultural products: crushed straw of grain crops (rye, barley, wheat, oats, buckwheat, and rice), flax shove, rice husk, crushed stalks of Jerusalem artichoke, and rapeseed. The second group is raw material waste in the form of fibers: flax, flax nails, jute, nettle, hemp, oil palm bark, coconut, and cotton. Figure 100 shows a view of plant waste.

Table 2.1 shows the characteristics of different recycled materials used in concrete. This cycle of reusing different materials in the concrete industry to achieve environmentally friendly concrete can be completed by using agricultural waste as much as possible. Today's agricultural waste is used in the concrete industry in different ways, the most important of which are the following: 1) Heat Transfer & Thermal Insulation, 2) Composite materials/bricks, 3) Cementitious/pozzolan/binder material, 4) Fiber reinforcement, 5) Aggregates (coarse and fine).

2.2.1 Heat transfer and thermal insulation

Walls are an important part of structures. Walls generally play an important role in heat and cold inside the environment. One of the applications of agricultural products can be the use of these products for thermal insulation. Good thermal insulation can minimize the speed of heat transfer between two different environments. Plant waste derived from agricultural products are widely found all over the world. Among the important sources of these materials are the European Union, Russia, Belarus, Ukraine, Vietnam, Malaysia, India, and China. Wastes from these products are considered excellent resources for obtaining efficient aggregates for thermal insulation materials [32]. These wastes can be divided into two groups based on their structure [32]: Group 1, waste includes crushed stems or husks of agricultural products: crushed straw of grain crops (rye, barley, wheat, oats, buckwheat, and rice), flax shove, rice husk, crushed stalks of Jerusalem artichoke, and rapeseed. The second group is raw material waste in the form of fibers: flax, flax nails, jute, nettle, hemp, oil palm bark, coconut, and cotton. Figure 100 shows a view of plant waste.

Table 2.1: Properties of recycled materials used in construction.

N.O.	Type of waste	Water absorption (%)	Density or specific gravity	Fineness modulus/particle size	Shape	Major chemical composition	Ref.
1	Crushed brick waste	15.4-19.1	2042 – 2160 (kg/m^3)	< 10		• Contains SiO_2=69% Al_2O_3=17% Fe_2O_3=6%	[33-39]
2	Crumb rubber waste	1.1-1.7	596 – 727 (kg/m^3)	0.9 - 5		• Contains Polymeric materials = 40% Carbon black=30% Steel=15%	[40-47]

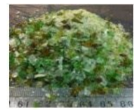
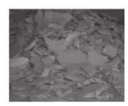
3	**Marine sediments waste**	**31.3**	**2637 (kg/m^3)**	**< 3**		**• Contains Sulfate=690mg/L Pb = 41mg/L Zn=10mg/L Ni=11mg/L**	**[48, 49]**
4	**Soda-lime glass waste**	**0 – 0.45**	**1680 (kg/m^3)**	**2.3 - 4.3**		**• Contains SiO_2=70% Na_2O=15% CaO=11%**	**[50-55]**
5	**Cathode ray tube (CRT) glass waste**	**0**	**3100 (kg/m^3)**	**2.7 - 3.4**		**• Contains SiO_2=51% Ba=13% K_2O=10% PbO=20-25%**	**[56-58]**
6	**Marble waste**	**0.05 – 0.12**	**2.68 - 2.70 (specific gravity)**	**< 20**		**• Contains SiO_2=5% CaO=52% LoI=41%**	**[46, 59-61]**
7	**Concrete slurry waste**	**38**	**1835 (kg/m^3)**	**< 5**		**• Contains SiO_2=33% CaO=37% Al_2O_3=8%**	**[62, 63]**
8	**Recycled concrete waste**	**3.1-14.2**	**2100 – 2400 (kg/m^3)**	**2.8 - 3.5**		**• Similar to natural aggregate • Contains: SiO_2, $CaCO_3$, Ca $(OH)_2$**	**[64-68]**
9	**Plastic waste**	**0**	**813 – 970 (kg/m^3)**	**3.2 - 3.5**		**• Contains Three main elements of C, H, O**	**[36, 69, 70]**

Figure 2.2 shows a view of plant waste (as insulating materials). The specific potential of these materials to be used as insulting materials is due to the microscopic nature of the cellular structure. Examining these materials' structure indicates regular partitions and the structural shape of a honeycomb (**Figure *2.3***).

Figure 2.2: Examples of agricultural waste raw materials for insulating materials: (A) rye straw, (B) flax boon, (C) Jerusalem artichoke, (D) rice husk, (E) jute fibers, (F) flax noils, (G) waste of cotton fibers, (H) coconut fibers, and (I) oil palm bar. [32]

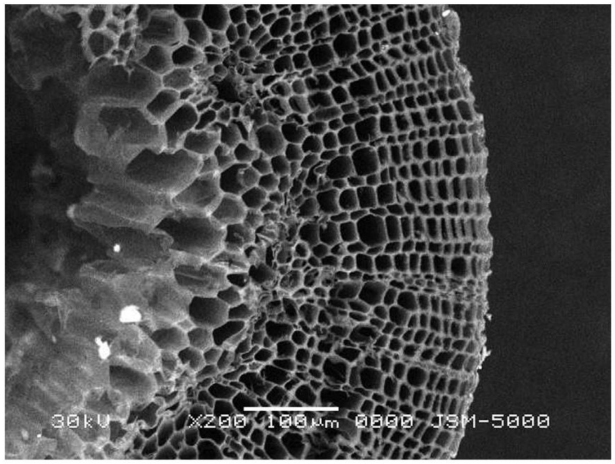


Figure 2.3: Cross section of a flax stem (fragment, 2003 magnification). [32]

In this regard, researchers studied the use of agricultural waste in heat transfer and thermal insulation. Ricciardi et al. [71]evaluated Sustainable panels made with industrial and agricultural waste. They investigated the thermal performance of recycled waste panels consisting of cork scraps, rice husk, coffee chaff, and tires. The first to third place for the best thermal results of panels made from waste materials were obtained as follows: 1) panel containing cork scraps 2) panel containing rice husk 3) panel containing coffee chaff. A very interesting hybrid solution was a panel composed of cork (60%), rice husk (20%), and coffee grounds (20%), which showed a thermal conductivity of 0.08 W/mK. Also, according to CED (considering the embodied energy), the best solution is a panel consisting of 56% cotton and 44% coffee straw (minimum CED and thermal conductivity). Ramlee et al. [72] investigated the potential of oil palm empty fruit bunch (OPEFB) and sugarcane bagasse fibers for thermal insulation application. They pointed out that in Malaysia, most household electricity (45%) is consumed by air conditioning. Inefficient insulation materials with poor thermal performance cause this high energy consumption. The results showed that OPEFB fibers and sugarcane bagasse have the potential to act as an efficient thermal insulation that significantly reduces additional energy consumption and, thus, costs. Generally, if the conductivity is less than 0.07 W/mK, it can be considered a thermal insulator. Mehrzad et al. [73] investigated sugarcane bagasse waste fibers as novel thermal insulation and sound-absorbing materials for sustainable building applications. Their results showed that thermal conductivity values varied between 0.034 and 0.042 W/Mk, and the sound absorption average (SAA) and noise reduction coefficient (NRC) displayed values between 0.26-0.64 and 0.27-0.62, respectively. They reported that SBW fibers perform well in low and medium frequency ranges. Johnson-Champoux-Allard statistical models also studied the samples' acoustic characteristics, and a good agreement with the experimental data was observed. Maderuelo-Sanz et al. [74] studied mechanical, thermal and acoustical evaluation of biocomposites made of agricultural waste for ceiling tiles. The raw materials used in this work were rice husk, vine pruning residues, cork (white cork, virgin cork, and expanded cork) and prickly pear. All of them were glued with a water-based acrylic resin in different proportions. Also, the sound absorption coefficient of biocomposites was measured experimentally using an impedance tube and modeled using the Zwikker and Kosten model in the frequency range from 200 Hz to 6400 Hz. The results of sound absorption coefficient values were close to 0.80 and showed an acceptable bending resistance for using them as false ceiling tiles. Therefore, these new categories of biocomposites offer sustainable biomaterials that can be an alternative to traditional acoustic ceiling panels, mainly composed of synthetic fibers or petroleum-based foams and resins. Ali et al. [75] studied date palm tree leaves and wheat straw as heat and sound insulation. They reported that the thermal conductivity for the fabricated samples was between 0.045 and 0.065 W/mK (at temperatures from 10 to 60 ◦C). In addition, the sound absorption coefficient for frequencies higher than 900 Hz is greater than 0.6 for almost all samples, indicating very good sound absorption behavior for these hybrid materials. Date palm tree leaves are also thermally stable up to about 213 ◦C. Asdrubali et al. [76] reviewed using unconventional sustainable building insulation materials. They stated that building insulation is usually done using materials obtained from petrochemicals (mainly polystyrene) or from processed natural resources with high energy consumption (glass and rock wool). This cannot be in line with moving towards sustainable development. They emphasized that the production of insulation made of natural materials should not be in conflict with the planting and harvesting of food crops, but should be focused on the use of waste and by-products of the agricultural sector. Also, the use of these non-conventional materials can reduce the use of petroleum and non-renewable resources. In addition, sugarcane, pineapple, and rice residues are mainly produced in places where there is a strong need to reduce summer cooling consumption. **Table *2.2*** shows the thermal properties of different agricultural products. The gray color indicates materials characterized by poor performance ($\lambda >$ 0.08 W/m). The green color is used for the best materials with $\lambda <$ 0.05 W/mK. Also, the blue color corresponds to items that have an average performance.

Table 2.2: Summary of thermal properties of different agricultural products.

#	Natural materials	Thermal conductivity (W/mK)
1	Banana	0.157–0.182
2	Bagasse	0.046–0.055
3	Corn cob	0.101
4	Cotton (stalks)	0.0585–0.0815
5	Date palm	0.072–0.085
6	Durian	0.064–0.185
7	Oil palm	0.055–0.091
8	Pecan	0.0884–0.1030
9	Pineapple leaves	0.035–0.042
10	Reeds	0.045–0.056
11	Rice	0.0464–0.566
12	Sansevieria fiber	0.132
13	Sunflower (cake from biorefinery)	0.0885–0.110
14	Sunflower (pitch)	0.0385–0.0501
15	Straw bale	0.038–0.067

2.2.2 Composite materials/bricks

At present, burying, burning, and abandoning agricultural wastes are among the environmental problems in many countries. Undoubtedly, the reuse of waste from agricultural products transformation industries is one of the available solutions to achieve sustainable development and preserve the environment. One of the applications of agricultural waste can be their use in the composite materials/bricks field, in this regard, a large part of agricultural waste can be returned to the reuse cycle.

In recent years, researchers have investigated the mentioned issue. Adazabra et al. [77] studied Infrared analysis of clay bricks incorporated with spent shea waste from the shea butter industry. They reported that using shea waste in clay material can be a useful way to manage shea waste. The compressive strength of brick materials decreased due to adding shea waste. Also, the amount of water absorption of bricks increased by adding shea waste to clay materials. They concluded that the bricks prepared from shea waste have the potential to be used in non-load-bearing mechanical applications. The potential performance benefits of brick development from clay materials mixed with spent shea waste were reported to include improved lubricating agents, economical firing, and the production of sustainable bricks. Singh et al. [78] investigated the performance behavior of agro-waste-based gypsum hollow blocks for partition walls (**Figure *2.4*** and **Figure *2.5***). They have studied combinations of gypsum samples based on agricultural waste for compressive, thermal, sound absorption, sound transmission loss, and fire-resistant properties. They reported that using rice straw reduces the density and compressive strength, making it useful for lightweight, non-load-bearing wall applications. The thermal conductivity of gypsum samples added to rice straw shows a decrease in thermal conductivity from 0.2 to 0.11 W/m K. Also, the sound characteristics, namely noise reduction coefficient (NRC), increase with the increase of rice straw from 25 to 45%. In addition, the decreasing trend of sound transmission class (STC) was reported from 37 to 28 dB. They emphasized that the agro-waste-based hollow gypsum blocks may be promising for drywall partitions due to their thermal insulation, low density, good acoustic properties, and fire resistance (**Figure *2.6***).

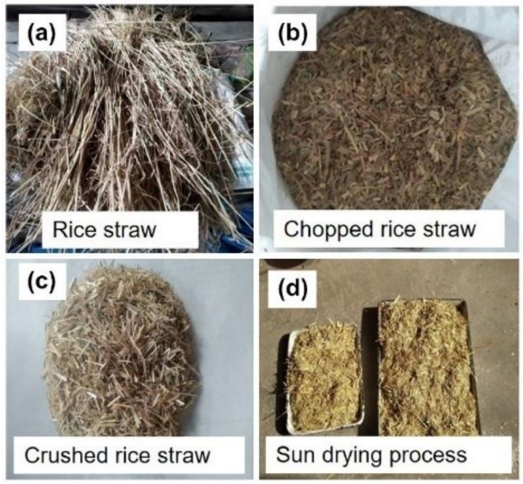


Figure 2.4: (a) Collected rice straws from farm fields; (b), (c) chopped and crushed rice straw; and (d) sun drying process for moisture removal [78].

Figure 2.5: Process, casting, sun drying, and wall construction of agro-waste gypsum blocks **[78]**.

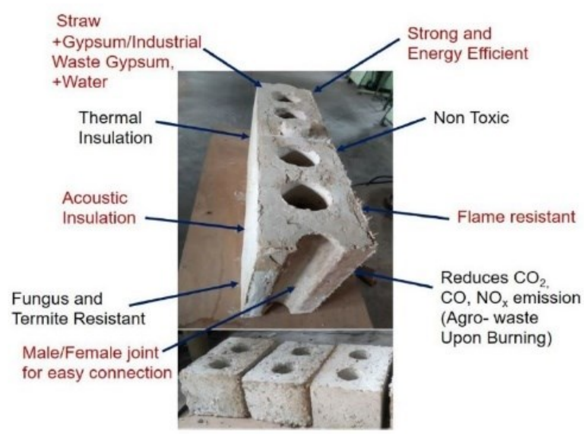


Figure 2.6: Features of agro-waste gypsum panel/blocks **[78]**.

Kumar and Vignesh [79] investigated green bricks containing bagasse ash. They reported that green brick can solve the problem of fly ash disposal to some extent, and in addition, the bricks produced were more economical and environmentally friendly. In their study, bricks were examined in terms of water absorption and compressive strength. The results show superior compressive strength and compliance with standards. In addition, a lighter brick was obtained by adding bagasse ash. Arshad et al.[80] investigated brick materials containing orange peel, coconut residue, and paper-mill residue (as binding material). They emphasized that clay materials are not available in other parts of the world and using these wastes can be an effective way to compensate for the lack of clay materials. They reported that reducing the clay content by combining orange peel and coconut waste can make the brick material lighter. Their results showed that the brick material meets the standard requirements for compressive strength. Kazmi et al. [81] investigated lighter and eco-friendly burnt clay bricks incorporating sugarcane bagasse ash. They reported that the manufactured bricks were lighter than conventional clay bricks. They also conducted mechanical and durability tests according to specific standards. The results indicate that the combination of sugarcane bagasse ash with clay forms a lightweight brick material. Also, the required compressive strength is achieved by mixing 5% of sugarcane bagasse ash with clay. In addition, by incorporating sugarcane bagasse ash into clay, flexural strength, and efflorescence increased. Damanhuri et al. [82] evaluated the mechanical properties of bricks containing rice husk ash (RHA) as a partial substitute for clay. The amount of replacement of RHA instead of clay in this study varied from 0% to 20%. According to the standards of Malaysia, compressive strength and water absorption were tested for the manufactured samples. They reported superior properties of samples made with clay and RHA. They emphasized that the inclusion of a higher amount of RHA in the clay reduced the strength due to cracking and thus reduced the bonding between the mixes. Likewise, their study showed that adding 10% RHA to clay materials increases the mechanical properties of brick materials.

According to the studies conducted by researchers in the field of using agricultural waste to make composite materials/bricks, it seems that agricultural waste can be a promising solution in the field of economic savings and most importantly reducing damage to the environment.

2.2.3. Cementitious/pozzolan/binder material

In recent years, the demand to reduce dependence on cement has increased due to the recognition of the harmful effects of cement production on the environment. Agricultural waste can be used as part of cement in concrete. In many studies, researchers focused on using agricultural waste as cementitious/pozzolan/binder material. **Table *2.3*** shows the characteristics of some agricultural wastes used in the cementitious/pozzolan/binder material field.

Table 2.3: Characteristics of agricultural waste used as cementitious /pozzolan/binder material.

Type of SCM	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Na_2O (%)	MgO (%)	K_2O (%)	LOI (%)	Ref.
Bamboo leaf ash	72.3-80.4	4.2-7.8	1.0-4.1	0.5-2.0	0.1-0.2	1.0-1.9	1.3-5.6	2.9-8.0	[52–54]
Wheat straw ash	4.9-87.9	9.4-24.4	0.1-4.6	0.1-1.3	0.1-5.4	0.6-4.6	0.7-24.7	1.1-29.0	[55–57]
Barley straw ash	21.2	10.0	2.8	3.5	4.1	-	38.0	-	[58]
Corn cob ash	37.0-66.4	11.6-13.0	2.4-7.5	1.2-4.4	0.3-0.4	2.1-7.4	4.9-15.0	22.5	[59–61]
Olive waste ash	11.8-25.8	42.4-54.8	2.6-8.5	1.4-5.7	0.2-0.5	3.2-4.4	0.3-9.3	9.5-11.7	[62–64]
Banana leaf ash	48.7	-	2.6	1.4	0.2	-	-	5.1	[64]
Elephant grass ash	56.2-67.8	0-2.6	22.1-23.1	4.0-6.1	-	-	2.0-7.4	2.6-4.4	[65]

Agwa et al. [83] investigated using sugarcane bagasse ash as a supplementary cementitious material to produce eco-friendly concretes. Investigations have shown that if SCBA is used in the amount of 5% to 10% instead of cement, the desired results of mechanical characteristics can be achieved. Bheel et al. [84] evaluated waste recycling coal bottom ash and sugarcane bagasse ash as cement and sand replacement material to produce sustainable concrete. In this study, SCBA was used to replace fine aggregate (FA) in the range of 0 to 40% by weight of FA, while CBA was used to replace the cement content in the range of 0 to 20% by weight of the total binder. In this study, workability, density, water absorption, and mechanical properties (in terms of compressive and tensile strength) were evaluated. A total of 204 samples (cubic and cylindrical) were made with a water-cement ratio of 0.54. Due to the pozzolanic nature of coal bottom ash and sugarcane bagasse ash, compressive and tensile strength was observed for certain concrete mixtures, and adding more CBA and SCBA decreased the strength. Jhatial et al. [85] investigated foamed concrete containing Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) as a partial replacement for cement. In this study, POFA was replaced by 0-35% of cement, and ESP was replaced by 0-5% of cement. Flowability, mechanical characteristics, and thermal performances (thermal conductivity and surface temperature) were investigated in this regard. They reported that the combination of 15-25% POFA with 5% ESP as a cement replacement resulted in an increase in the mechanical strength of concrete. Although the use of POFA can reduce thermal conductivity, the content of POFA should be limited to 15-25% to avoid excessive heat absorption by the outer surface of the concrete. In general, they reported the optimal mixture to be 15% of POFA with 5% of ESP.

Farrant et al. [86] investigated the influence of sugarcane bagasse ash and silica fume on concrete's mechanical and durability properties. In this study, potassium hydroxide (KOH), which is used as an alkaline activator, is considered to increase the reactivity of ash with the possibility of high-volume SCBA content. The results showed that using sugarcane bagasse ash in a ternary mixture with silica fume creates less porous concrete and significantly increases performance. With the replacement of 30% SBA and 10% silica fume, the maximum mechanical strength and the lowest permeability performance were observed, outperforming the control concrete and the binary blended cement concrete containing only SBA. Channa et al. [87] investigated concrete containing sugarcane bagasse ash (5%, 10%, and 15%) and rice husk ash (10%, 20%, and 30%) as a substitute for cement (**Figure *2.7***). They reported that using 5% SCBA and 5% RHA as cement replacement material individually or in combination in concrete can provide good results for structural applications in concrete (**Figure *2.8*** and **Figure *2.9***).

Figure 2.7: Material collection and preparation [87].

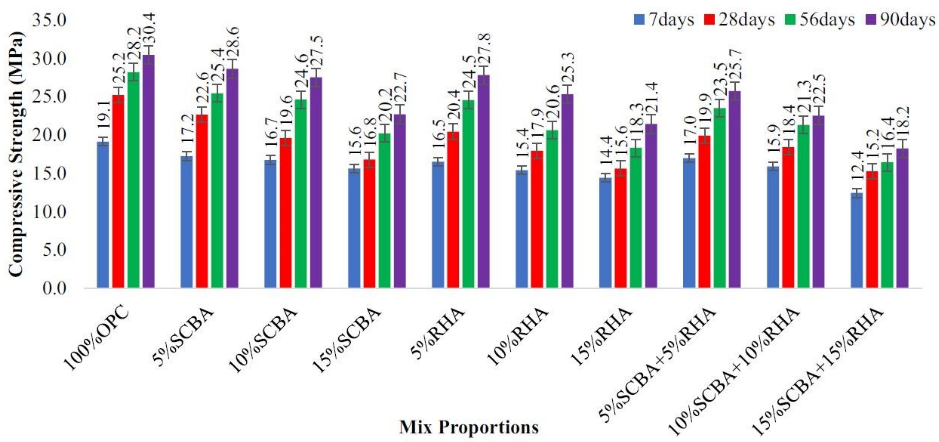


Figure 2.8: Compressive strength of concrete containing SCBA and RHA [87].

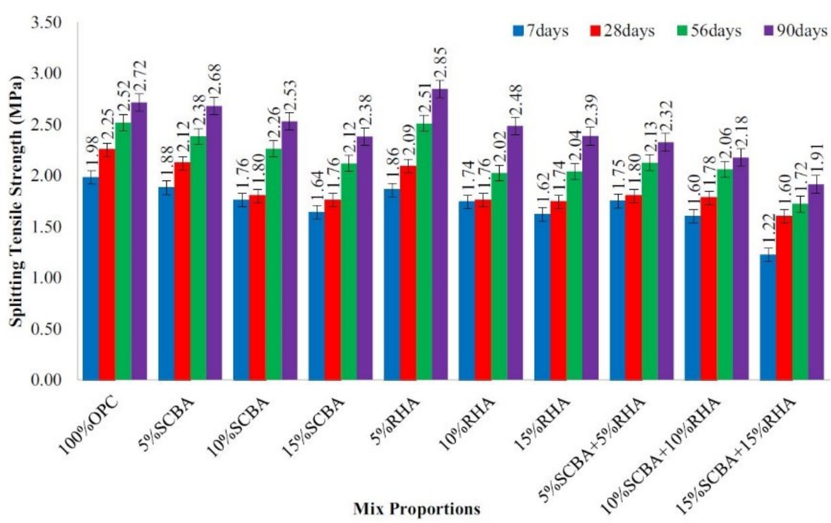


Figure 2.9: Splitting tensile strength of concrete containing SCBA and RHA [87].

2.2.3 Fiber Reinforcement

According to the goal of sustainable development, the construction industry needs to use standard materials to move towards a cleaner environment. In this regard, using natural fibers can be considered in the concrete industry to achieve desirable concrete with mechanical characteristics equal to previous destructive materials.

In this regard, the researchers turned their attention to using different types of agricultural waste as fiber reinforcement in concrete types. Krishna et al. [88] used coconut coir fiber and sisal fiber to improve the ductility and strength of concrete. They reported that using 1.5% coconut coir fiber is optimal for increasing the ductility and strength of concrete. In addition, when used with sisal fiber, it helps increase concrete's bearing capacity. Long and Wang [89] investigated the mechanical properties of concrete containing Masson pine needle fiber (MPNF). They concluded that MPNF can improve compressive strength, tensile strength, modulus of rupture, toughness, and ductility of concrete. Thomas and Jose [90] investigated the effect of sisal fiber on concrete. Their investigation on composites reinforced with sisal fiber concluded that this type of fiber could be used well in the structural elements of urban and rural buildings. Even these fibers can be an alternative to steel materials, which are dangerous for humans and animals. Also, the production of sisal fiber was compared with the production of synthetic fibers and mineral asbestos, and they concluded that sisal fiber is cost-effective in terms of production and has social and economic benefits. Pirmohammad and Mengharpey [91] investigated two natural fibers (**Figure 2.10**) in WMA (warm mix asphalt) concretes for their effect on failure resistance. The results showed that kenaf and basalt fibers improve the fracture resistance of WMA mixtures. Adding 0.3% of kenaf and basalt fibers to WMA concrete positively affected failure resistance. In addition, WMA mixtures containing kenaf fibers performed better than mixtures containing basalt fibers.

a) kenaf b) Basalt

Figure 2.10: a) Kenaf and b) basalt fibers with a length of 0.8 mm were used for preparing the reinforced WMA mixtures [91].

Chen et al. [92] compared the structural performance, cost-effectiveness, environmental effects, advantages and disadvantages of natural fiber-reinforced polymer (NFRP) with carbon fiber-reinforced polymer (CFRP). They reported that since NFRP sheets and concrete have similar elastic moduli, NFRP-reinforced RC beams fail at FRP rupture and achieve higher ultimate loads and ductility than CFRP-reinforced beams. Regarding structural performance, cost-effectiveness and environmental impact, four-layer NFRP laminates with a cross-sectional area of 6.67 times that of CFRP sheets can achieve favourable results. Asim et al. [93] investigated the comparative use of natural fibers (**Figure *2.11***) in lightweight concrete as thermally efficient building materials. In this regard, thermal conductivity tests, scanning electronic microscope tomography (SEM), and microscopic images for interfacial bonding of fibers with concrete were investigated. They reported that natural fibers provide improved thermal insulation. Thermal conductivity results showed that by increasing the percentage of natural fibers (Jute, Coconut, Sugar cane, Sisal) in concrete, thermal insulation properties increased and compressive strength decreased. In addition, TGA showed that jute fibers, sugar cane, and basalt RC have better thermal stability compared to plain concrete up to 50°C, which is suitable for the climate of South Asian countries. However, the samples reinforced with Sisal and coconut fibers have relatively lower thermal stability. Also, mixing 2.5% of Coconut and Jute improved the compressive strength and thermal insulation. In addition, they reported on microscopic images that adding natural fibers to lightweight concrete leads to increased concrete porosity, which they introduced as one of the cases of reducing thermal conductivity (**Figure *2.12*** and **Figure *2.13***).

Coconut (C) Sugar cane (SC) Jute (J) Sisal (S) Basalt (B)

Figure 2.11: The fibers used [132].

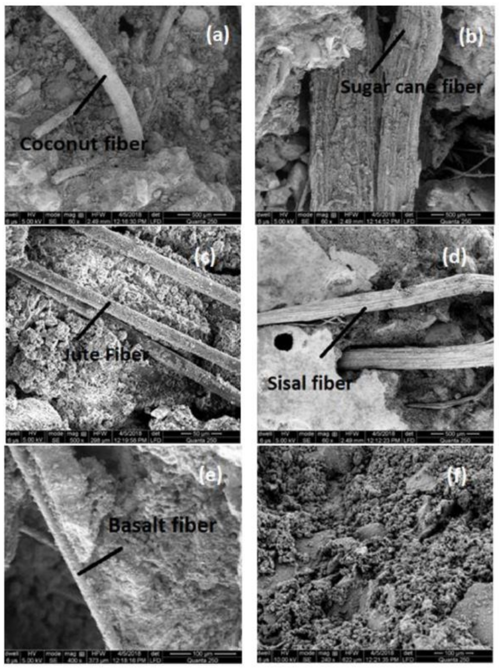


Figure 2.12: SEM images of natural fibers RC and plain concrete, (a) Coconut (C) fiber RC, (b) Sugarcane (SC) fiber RC, (c) Jute (J) fiber RC, (d) Sisal (S) fiber RC, (e) Basalt (B) fiber RC and (d) Plain concrete [93].

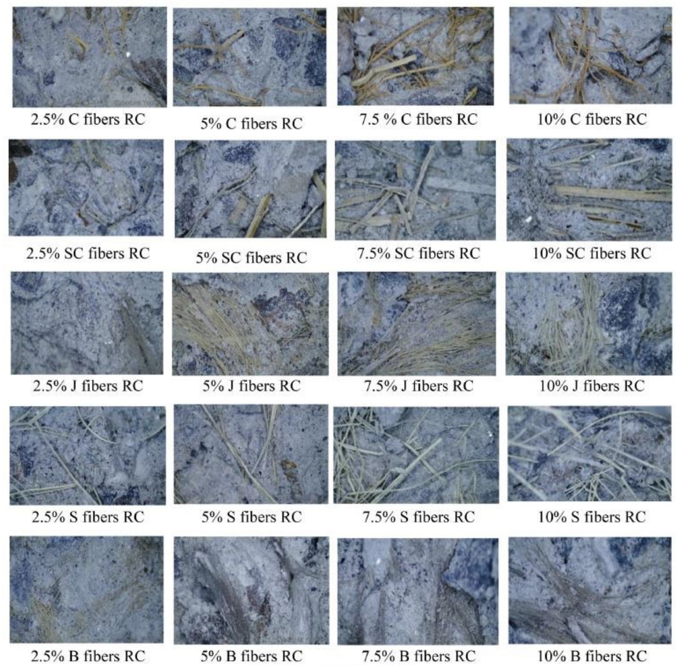


Figure 2.13: Microscopic images of fibers RC and plain concrete [93].

In the construction industry, shear strengthening of reinforced concrete beams is common. Alam and Riyami [93] evaluated the shear strengthening of the reinforced concrete beam using natural fiber-reinforced polymer laminates (**Figure *2.14*** and **Figure 2.15**). They stated that the high cost of CFRP sheets and the corrosion of steel sheets are among the disadvantages of these materials. Therefore, to cover this weakness, they investigated the composite plate based on natural fibers to replace the shear reinforcement of the reinforced concrete structure. To achieve the objectives of our study, plates were made using kenaf, jute, and jute rope fibers in treated and untreated conditions. The results showed that shear-reinforced beams with kenaf, jute, and jute rope composite plates (treated) showed 35, 36, and 34% higher failure load than the control beam. Also, beams reinforced with natural fiber composite sheets showed higher ductility and breaking loads than CFRP sheets.

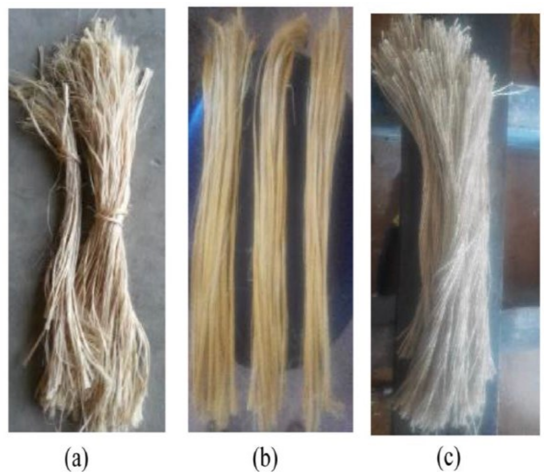


Figure 2.14: Prepared fibers; (a) kenaf fiber, (b) jute fiber and (c) jute rope [93].

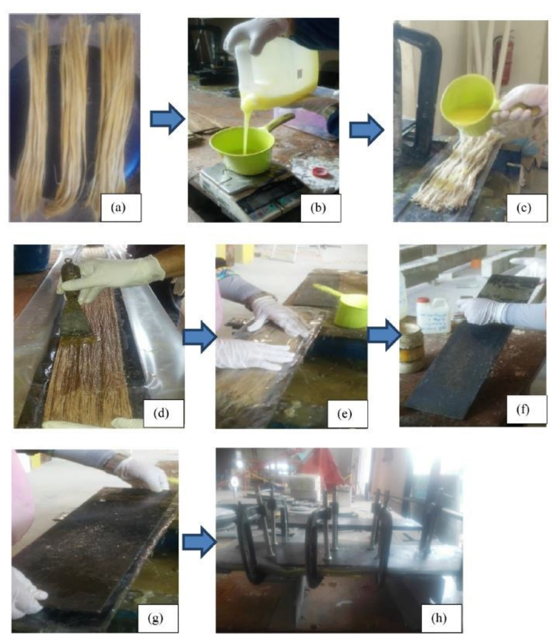


Figure 2.15: Fabrication process of natural composite plate; (a) Dividing fibers, (b) Weighting adhesive, (c) Pouring the adhesive, (d) Pressing the fiber, (e) Covering the mould with plastic, (f) Greasing the top plate, (g) Cover the mould with top plate and (h) Compressing the composite plate by clamps [93].

Lara et al. [94] investigated plain foamed concrete (PFC) and fiber-reinforced foamed concrete (FRFC). Their study used henequen fibers (treated and untreated) at dosages of 0.5%, 1%, and 1.5% (Error! Reference source not found.). Their results showed that using natural fibers improved c ompressive and tensile strength and plastic behavior. Also, based on their results, there was no significant drop in strength after the peak resistance under compressive loading (**Figure** ***2.17*** and **Figure 2.17**). Under tensile loading, the fibers significantly increased the tensile strength of FRFCs and prevented the specimens from snapping, which was in contrast to the brittle behavior of PFCs (**Figure** ***2.19*** and **Figure** ***2.20***). The improvement in tensile behavior was greater in the mixtures containing treated henequen fibers, which they attributed to the increased fiber-matrix bonding produced by the alkali treatment. The increase in tensile behavior was higher when treated Hinkone fibers were used, which was attributed to the increased fiber-matrix bond produced by alkaline treatment. In addition, they reported higher energy absorption of FRFC compared to PFC, which they attributed to the increased toughness and ductility of the fibers.

Figure 2.16: (a) Henequen plant; (b) henequen fibers and (c) henequen fibers chopped to a length of 19 mm [94].

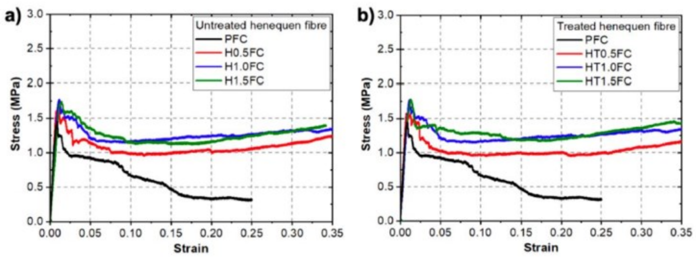


Figure 2.17: Typical uniaxial compression stress–strain curves [94].

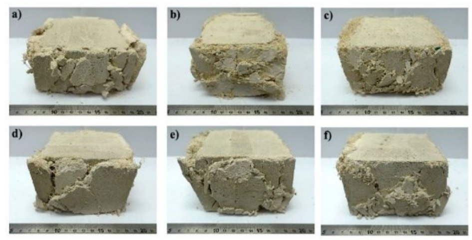


Figure 2.18: Deformation of the representative foamed concrete specimens at 0.35 compressive strain, reinforced with untreated henequen fiber: (a) H0.5FC; (b) H1.0FC and (c) H1.5FC; with treated henequen fiber: (d) HT0.5FC; (e) HT1.0FC and (f) HT1.5FC and with PP fiber: (g) PP0.5FC; (h) PP1.0FC and (i) PP1.5FC [94]

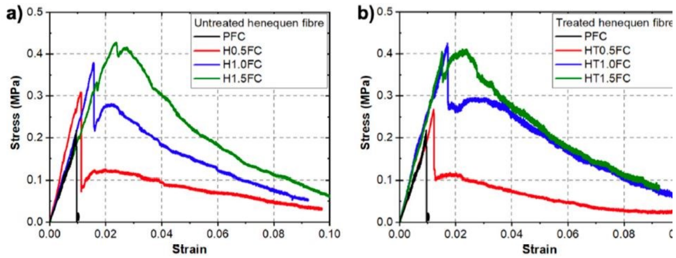


Figure 2.19: Typical uniaxial tensile stress–strain curves [94].

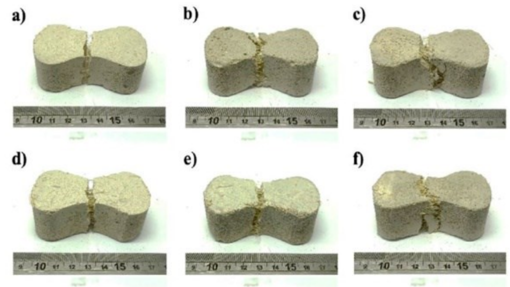


Figure 2.20: Figure 20. Representative foamed concrete specimens after the tensile test, reinforced with untreated henequen fiber: (a) H0.5FC; (b) H1.0FC and (c) H1.5FC; with treated henequen fiber: (d) HT0.5FC; (e) HT1.0FC and (f) HT1.5FC and with PP fiber: (g) PP0.5FC; (h) PP1.0FC and (i) PP1.5FC [94].

2.2.4 Aggregates

Indiscriminate use of natural aggregates in the construction industry has led to this industry paying more attention to alternative aggregates to produce cleaner and environmentally friendly concrete. In this regard, the waste from the agricultural industry can help the concrete industry. Therefore, in recent years, researchers have studied using agricultural waste as natural fine grain and natural coarse grain.

2.2.4.1 Coarse

Some researchers used agricultural waste as a substitute for coarse aggregate. Gunasekaran et al. [95] investigated and evaluated the results of coconut shell concrete beams subjected to torsion and compared them with conventional concrete beams (**Figure *2.21*** and **Figure *2.22***). They evaluated 8 arrows, including 4 beams containing coconut shells and 4 without coconut shells. They reported that coconut shell concrete samples have higher ductility than conventional concrete samples. The crack width at the initial crack moment for normal and coconut shell concrete with the respective reinforcement ratios is almost similar.

Fig. 1. (a) Collected CS and (b) crushed CS aggregate.

Figure 2.22**: (a) Collected CS and (b) crushed CS aggregate [95]**

Fig. 7. Tested CC and CSC beams.

Figure 2.21**: Tested CC and CSC beams [95]**

In another study, Gunasekaran et al. [96]studied the effects of three types of curing on coconut shell aggregate concrete for long-term performance (**Figure** ***2.23***). They reported that the water absorbed by the coconut shell is stored during the soaking period, and the pore structures in the coconut shell behave like a reservoir. Also, most compressive strength development occurs in the early stages and continues to increase as the samples age. Coconut shell aggregate concrete does not deteriorate after encapsulating coconut shell aggregates in the concrete matrix. Biological decay was not observed because the samples gained strength even after 365 days.

Figure 2.23: Sizes of coconut shell [96].

Falade [97] investigated periwinkle shells as coarse aggregate in concrete. The results of this study indicate that compressive and flexural strength decreases with increasing the ratio of PWS to granite in standard mixtures. Falade and Ikponmwosa [98] investigated the behavior of lightweight concrete containing periwinkle shells at elevated temperatures. They concluded that the compressive strength of concrete decreases with increasing water-cement ratio and temperature but increases with curing age and cement content, while density decreases with increasing temperature. Lightweight concrete containing periwinkle shells is only suitable for structures exposed to temperatures below 300 ^{0}C. Muthusamy and Nordin [99] investigated the concrete containing Rubber Seed Shells as coarse grain. Rubber Seed Shell was replaced with coarse gravel at 0, 5%, 10%, 15%, and 20%. The results showed that the workability, compressive strength, and flexural strength decreased with the increased shell replacement level of crushed rubber grains. However, a mixture containing about 10% of crushed rubber seed husks is suitable for concrete work. Jayaprithika and Sekar [100] investigated Stress-strain characteristics and flexural behavior of reinforced Eco-friendly coconut shell concrete (**Figure *2.25***). They reported that the flexural behavior of under-reinforced and over-reinforced coconut shell concrete designed by the limit state method using the actual stress-strain behavior is analogous with the experimental values. The deflection and crack width of coconut shell concrete is comparable with the permissible values given by IS 456:2000, ACI-318, and EC 2:1992. (**Figure *2.24***)

Figure 2.25**: Sizes of CS used in concrete [100].**

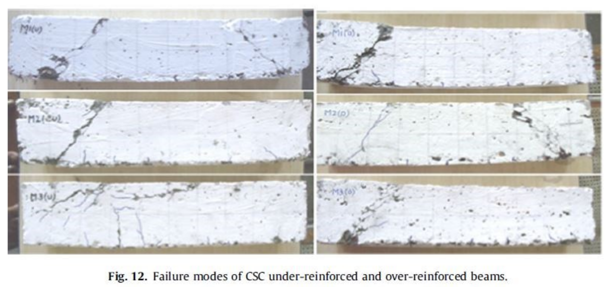


Figure 2.24**: Failure modes of CSC under-reinforced and over-reinforced beams [100].**

Pinto et al. [101] investigated Corn cob lightweight concrete for non-structural applications (**Figure *2.26***). They reported that corn cob concrete may have the adequate material properties required for lightweight concrete for non-structural application purposes.

(a) Adding (b) Curing (c) Unmoulding

Figure 2.26: Processing of the corn cob concrete samples for the compression test [101].

Maghfouri et al. [102] investigated drying shrinkage prediction models for lightweight concrete containing Oil palm shell (OPS) as coarse aggregate. Their study compared actual drying shrinkage at early and long-term ages (275 days) against theoretical results from drying shrinkage prediction models such as ACI209R, EN1992, GL2000, B3 and SAK. Comparison between the test results and predicted results indicated that EN1992 was the most precise model at early ages and GL2000 at long-term ages.

2.2.4.2 Fine

Some researchers used agricultural waste as a substitute for fine aggregate. Loh et al. [102] reviewed sugarcane bagasse in cement composites and emphasized that this material can be used as a fine aggregate. Modani and Vyawahare [103] studied concrete containing 0%, 10%, 20%, 30%, and 40% of untreated bagasse ash as fine particles. The results showed that the compressive strength results represent that the mixes' strength with 10% and 20% bagasse ash increases at later days (28 days) compared to 7 days, which may be due to the pozzolanic properties of bagasse ash. Also, the sorptivity test result shows that the sorptivity coefficient increases with an increase in the percentage of bagasse ash, indicating more permeable concrete due to the porous nature of SCBA and its impurities. They reported that in its purest form, bagasse ash can be a potential ingredient of concrete since it can be an effective replacement for cement and fine aggregate. Sales and Lima [104] investigated concrete containing sugarcane bagasse ash as fine aggregate.

The results showed that SBA samples show physical properties similar to natural fine aggregates. Also, several heavy metals were found in the samples containing SBA, which seems that limiting the use of these materials as fertilizers is necessary. Mortars produced with SBA instead of natural fine grain showed better mechanical results than the reference samples. SBA can be used as a partial substitute for sand in concretes made with Portland cement modified with cement slag. Nóvoa et al. [105] investigated the mechanical characterization of lightweight polymer mortar modified with cork granulates. This study used cork in the replacement ratio of 0% to 45%. They reported a drop in compressive and flexural strength. They emphasized that the modified mortar properties seem to follow a rule of mixtures in terms of their components. Panesar and Shindman [106] investigated the mechanical, transport and thermal properties of mortar and concrete containing waste cork. In their study, they replaced waste cork with 0 to 20% fine grain. They reported that the optimum 28-day compressive strength of 24.3 MPa was obtained for the mixture containing 10% waste cork with a 0.5-1 mm size. Increasing the size of the cork up to 5 mm can lead to decreased resistance and increased porosity. They also emphasized that finer cork sizes were most beneficial to achieve optimum mechanical and transport properties; however, high permeability values indicate that concrete-cork composites considered in this study may be vulnerable to poor durability performance. Ganiron [107] studied concrete containing sawdust as a natural fine grain. This study emphasizes that the higher saturation of water deposits in the sawdust particles during curing tends to weaken the sample.

The use of agricultural waste in controlled low-strength materials (CLSM) is a suitable option for these wastes. Controlled Low-Strength Materials (CLSM) is a self-compacted, self-leveling cementitious material with 8.3 MPa or less compressive strength.

Mneina and colleagues [108] investigated the engineering properties of controlled low-strength materials containing treated oil sand waste. This study showed that CLSM mixtures containing TOSW met the limits and requirements of ACI Committee 229 for CLSM without environmental hazards. The incorporation of TOSW increases the flowability of all mixtures and thus reduces the water demand to reach the required flowability, which increases the compressive strength of mixtures containing TOSW and FA. They reported that the successful incorporation of TOSW into the CLSM mixture provides a safe recycling method for sand and oil sand wastes while reducing the environmental footprint of the oil sands and construction industry. Kuo et al. [109] studied the use of waste oyster shells (WOS) at 0%, 5%, 10%, 15%, and 20% in CLSM. The results showed that the mixture containing 5% WOS exhibits better compressive strength than the control mixture. The results of this study show that the overall compressive strength of CLSM decreases with increasing WOS sand replacement. They emphasized that WOS sand can be a resource of pure calcareous materials and effective in the replacement of sand, indicating the appropriate application of oyster shells is feasible to use in CLSM. Ismail and Jaeel [110] investigated the use of undesirable wild giant reed biomass to replace aggregate in concrete (**Figure *2.27***). The results of this study showed that the compressive strength of 28 days for mixtures containing GRA and GRF (substitution of 7.5%) increased to 7.96% and 2.47%, respectively. The results confirm that using giant reeds offers a sustainable approach to solving the pollution problems that arise from accumulating this excessively aggressive species in the production sites. Ozturk and Bayrakl [111] investigated lightweight concrete containing Tobacco Wastes. They reported that the samples produced based on the values of consistency, unit weight, porosity, compactness, compressive and thermal conductivity are in the light concrete class. They reported that the unit weight of lightweight concrete material samples ranged between 0,50 – 0,56 kg dm^{-3}, compressive strength values ranged between 0,20 - 0,60 N mm^2, and thermal conductivity coefficients ranged between 0,194 – 0,210 W m^{-1} K^{-1}.

Figure 2.27**: Air-dried giant reed stakes [110]**

2.3 Discussion

In recent years, the planet's ecosystem has undergone many changes. Humans have caused much environmental damage due to these actions: damage to the ozone layer, global warming, acid rain, climate change, etc. The time has come for countries to move faster toward sustainable development. Due to the major contribution of the construction industry to the pollution of the planet, it should make a double effort to compensate for the damages caused to the planet. As a subset of the construction industry, we know the concrete industry, which can be the main culprit of pollution in the construction industry. The concrete industry consumes huge natural resources such as aggregates, and on the other hand, due to the need of this industry to use cement, it produces CO_2. It seems that with proper planning, the latent potential in the agricultural industry, which includes different types of waste, can be directed toward the concrete industry. In recent years, agricultural waste has gained attention in the concrete industry due to its cost-effectiveness, environmental friendliness, flexibility, and ability to meet expectations in terms of strength.

Many studies focused on the use of these valuable wastes in various fields, which include: 1) Heat Transfer & Thermal Insulation, 2) Composite materials/bricks, 3) Cementitious/pozzolan/binder material, 4) Fiber reinforcement, 5) Aggregates (coarse and fine). Based on the existing standards, most studies investigate the thermomechanical properties of different materials and composites. Standard test parameters for checking insulation and particle board usually include density, MOE, MOR, and thermal conductivity. Based on the investigations, thermal conductivity values of 0.054-0.143 W/mK have been observed, which meet the requirements of insulating materials according to BS874-2 [112]. Also, the compressive strength in the brick field for non-load-bearing solid-fired clay bricks is about 3 to 5 MPa.

On the other hand, the compressive strength of load-bearing bricks has been reported as 5 to 10 MPa. Interestingly, it is even possible to use the burnt remains of agricultural waste in concrete, which can be done according to the IS 456:2000 standard [113]. The use of agricultural waste as fibres shows positive results, but the only major weakness of these cases is more related to durability. Also, replacing agricultural wastes with natural aggregates shows significant results, which seems to produce more affordable concrete that meets the existing standards in terms of strength.

Therefore, it can be predicted that the demand for agricultural waste will increase in the coming years. Studies have been conducted so far on various aspects of using agricultural waste in concrete, but it seems that there are many gaps that researchers are expected to pay more attention to in the next year.

2.4 Conclusion

Based on the review of previous studies, these results were obtained:

- Studies show that agricultural waste has much potential to be used as an insulating material because of the microscopic nature of the cellular structure. The structure of these materials indicates regular partitions and the structural shape of a honeycomb.
- I am using these waste materials in Malaysia (about 45% of household electricity consumption is through air conditioning) as thermal insulation has brought positive results.
- The review of previous studies showed that the use of agricultural waste in different fields can significantly affect the economic issue of the concrete industry and bring affordable concrete for concrete.
- The mechanical characteristics of concrete made with agricultural waste in most studies met the requirements of the desired regulations.
- The review of previous studies indicates that the use of agricultural waste instead of fine and coarse aggregates simultaneously can have a greater effect.
- Agricultural waste can greatly reduce the embodied energy of other harmful materials in this industry.
- Using agricultural waste materials and products as raw materials in constructions and buildings can be a suitable solution from a technical and commercial point of view as an alternative renewable material.

It seems that there are still different aspects of concrete containing agricultural waste that researchers can address in future studies. For example, using artificial intelligence methods to examine the various characteristics of these types of concrete can provide useful information. On the other hand, more attention can be paid to increasing the durability of concrete containing agricultural waste by combining it with other materials. Investigating different curing conditions, the use of new nanomaterials, the simultaneous use of industrial and agricultural waste, etc., can be considered for future research.

CHAPTER 3: Using Agro-Waste in Production of Concrete Tile

The management of waste, particularly the disposal of agricultural waste (known as agro-waste), is a global challenge due to associated environmental concerns. Utilizing this agro-waste in the construction industry is a potential solution to enhance the sustainability of the agriculture and construction sectors. However, previous studies showed that incorporating agro-waste in concrete as a substitute for different components adversely affects its mechanical and durability performance. Hence, this study investigates the feasibility of using agro-waste as a partial replacement for coarse aggregate in producing concrete tiles. Results demonstrate that agro-waste incorporation reduced mechanical properties while satisfying performance limits. On the other hand, Agro-waste incorporation lowered concrete density, promoting the production of eco-friendly lightweight concrete tiles for several building applications.

3.1 Introduction

Nowadays, producing cement concrete tiles in the construction industry is to provide versatile and cost-effective material for various scientific applications [114, 115]. Concrete tiles are specifically engineered to exhibit exceptional strength, durability, and resistance to wear and tear [116, 117]. The production process focuses on creating concrete tiles that can withstand heavy loads, extreme temperature fluctuations, and harsh environmental conditions, ensuring their long-term viability and reliability in scientific settings [118].

The utilization of agro-waste in concrete has gained significant attention in recent years, as evidenced by numerous studies in the literature. Researchers have explored agro-waste materials as potential replacements for traditional aggregates and cement production in concrete [119, 120]. Rice husk ash (RHA) [121], sugarcane bagasse ash (SCBA) [122], and coconut shell ash (CSA) [123] have been investigated as partial replacements for aggregates, while rice straw ash (RSA) [124], corn cob ash (CCA) [125], and bamboo leaf ash (BLA) [126] have been considered as partial replacements for cement. These studies have demonstrated that incorporating agro-waste materials in concrete can positively affect fresh and hardened concrete properties. Using agro-waste has shown lower workability, reduced bleeding and segregation, enhanced compressive strength, and improved durability [127]. Moreover, using agro-waste in concrete offers environmental benefits, such as waste reduction, lower carbon footprint, and potential economic advantages [128]. However, challenges related to standardization, quality control, and long-term performance must be addressed for the widespread implementation of agro-waste concrete in the construction industry [129]. Further research is necessary to optimize agro-waste use and overcome these limitations.

Using agro-waste materials in concrete has demonstrated promising potential, but several gaps and challenges that necessitate attention and resolution remain. A fundamental gap exists in the absence of standardized protocols and quality control measures for incorporating agro-waste materials into concrete [130]. The inherent variability in agro-waste characteristics, encompassing particle size, chemical composition, and pozzolanic activity, poses significant challenges in attaining consistent and dependable outcomes [131]. Furthermore, comprehensive investigations into agro-waste concrete's long-term performance and durability are still lacking. It is imperative to thoroughly comprehend the potential adverse effects of agro-waste usage, such as excessive shrinkage and diminished bond strength. Future research endeavours should prioritize resolving these gaps to facilitate the successful use of agro-waste materials in concrete and establish guidelines and standards for their secure and reliable implementation in construction applications [132].

The present study evaluates the optimal level of agro-waste as a replacement of natural aggregate in concrete to achieve acceptable mechanical properties and durability of agro-waste in concrete tile. This research seeks to foster mutual benefits for the construction and agricultural sectors and aims to enhance overall efficiency. By substituting agricultural wastes, either partially or entirely, for natural gravel, energy and natural resources can be conserved, construction costs can be reduced, and agricultural waste disposal issues can be addressed. Moreover, this study's findings and characteristics of concrete tiles incorporating agricultural wastes will promote an environmentally friendly approach to the concrete production sector.

3.2 Experimental programs

3.2.1 Material

General use (GU) hydraulic cement, according to CSA-3001-03, was used as the binding material. Fly ash (FA) was used in all concrete mixtures. All concrete mixtures used fly ash (FA) as a replacement of as a partial replacement for cement. Table 3.1 shows the chemical composition of both cement and FA. Natural riverside sand with a fineness modulus of 2.70, a specific gravity of 2.51, and water absorption of 2.73%, respectively, was were used as a fine aggregate, . Crushed stone with specific gravity, water absorption, and maximum nominal size of 2.69, 1.3%, and 12.5 mm according to ASTM C33 [133], respectively, was used as the coarse aggregate. The used agro-waste (topinambour) with specific gravity, and a maximum nominal size of 0.375, and 15 mm, respectively, was used as a volume replacement of coarse aggregate at rates 5, 10, 15, and 20 %. Polycarboxylate high range water reducing admixture (HRWRA) with a specific gravity of 1.08 g/cm3 was used to adjusted flowability within the range of 100–230 mm100–230 mm range according to the ASTM C143 [134]. Hardening accelerating admixture with a specific gravity of 1.17 g/cm3 was used to adjust the setting time between 45 min to 6.5 hours according to [135].

Table 0.1: Chemical and physical properties of cement.

Item	GUL	FA
SiO_2 (%)	19.80	48.9
Al_2O_3 (%)	4.90	23.3
Fe_2O_3 (%)	2.30	14.9
CaO (%)	62.30	3.8
MgO (%)	2.80	0.7
Na_2O (%)	0.34	0.6
SO_3 (%)	3.70	0.2
C_3S (%)	57.00	-
C_2S (%)	14.00	-
C_3A (%)	9.00	-
C_4AF (%)	7.00	-
Loss in the ignition (%)	1.90	-
Specific gravity	3.15	2.50

3.2.2 Mix properties

Initially, all dry ingredients, including gravel, sand, agro-waste, cement, and FA, were mixed for 1 min to ensure a homogeneous mix. Then, half of the mixing water, HRWRA, and accelerator were added gradually to the mixture in 1 min. The mixture was kept at rest for 1 min. After the rest, the remaining water, HRWRA, and accelerator were added, and mixing continued for 3 min until a homogenous mixture. Table 3.2 shows five mixtures of concrete with different percentages of agro-waste. In all mixtures, water-to-cement ratios (w/c) were set at 0.35. Additional water was added to the composite for the amount of agro-waste absorbed by the mixture. The cementation content was 400 kg/m3. The replacement level for FA was 10 % by the weight of the cementation content. The mixtures were coded according to the percentage of agro-waste. For example, W10 is a concrete mix with 10 % agro-waste replaced as coarse aggregate. The dosage of the superplasticizer was 0.4% in all mixtures, but the dosage of the accelerator was adjusted according to the amount of agro-waste to meet the acceptable setting time.

Table 0.2: mixture Properties of agro-waste concrete tile

Mix Code	Cement (kg/m^3)	W/B	Water (kg/m^3)	Fly ash (kg/m^3)	Gravel (kg/m^3)	Sand (kg/m^3)	HRWRA (%)	Accelerator (%)	Agro-waste (%)
Control Mix	360	0.35	140	40	741	1133	0.4	0	0
W5	360	0.35	140	40	704	1133	0.4	0.2	5
W10	360	0.35	140	40	667	1133	0.4	0.4	10
W15	360	0.35	140	40	630	1133	0.4	0.6	15
W20	360	0.35	140	40	593	1133	0.4	0.8	20

3.2.3 Tests

The flowability of concrete was evaluated using the slump test according to ASTM C143 [184], "Standard Test Method for Slump of Portland Cement Concrete", which specifies concrete slump value between 15 and 230 mm.

Cylindric specimens 100 mm in diameter and 200 mm in length were used to evaluate compressive strength and tensile strength at ages 7 and 28 days according to **ASTM C39** [136]“Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens” and **ASTM C496**

[137]“Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,” respectively.

The flexural strength of the agro-waste concrete was determined based on ASTM C78 [138] “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)”. The concrete specimens were subjected to a three-point loading setup and three-millimeter-thick, twenty-millimeter-wide plywood cushioning was placed between the specimen and supports. The load was gradually applied until the specimen failed. For each specimen, a load versus deflection curve was recorded and plotted. The force causing the concrete specimen to fail was recorded.

The shrinkage of agro-waste concrete was measured on 75 × 75 × 285 mm specimens according to **ASTM C157** [139] “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.” To reduce water evaporation from the surface, specimens were maintained in plastic bags inside the mould for seven days. Initial length readings were recorded after demolding, and the specimens were sorted at the lab conditions (i.e., temperature 22 °C and relative humidity 50 ± 3 %). The readings were taken daily until there was no change in length.

The weight of 100 mm diameter and 50 mm cylindrical specimens were measured after being placed in the oven at 110 °C for 24 hrs. Then, the specimen was submerged in water for 72 h, and the weight was recorded according to **ASTM C1585** [140]“Standard Test Method For Measurement of Rate of Water Absorption by Hydraulic-Cement Concretes”. The density of the concrete specimens was measured according to **ASTM C138** [141] Standard “Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.”

The ultrasonic pulse velocity test was used to determine variations in the density of agro-waste concrete and detect any internal defects, according to **ASTM C597** [142] standard “Standard Test Method for Pulse Velocity Through Concrete.”

Surface resistivity measurements were taken at 28 days using a commercially available 4-point Wenner probe surface resistivity meter according to **AASHTTO TP -95-11** [143] “Surface Resistivity Indication of concrete’s Ability to Resist Chloride Ion Penetration.” It consists of four electrodes arranged in a straight line and spaced at equal distances of 3.8 mm. The two inner probes measure the AC induced by the exterior probes and the potential drop (V) resulting from it. After removing the specimens from the curing room, the test procedure began. Following that, four points (0°, 90°, 180°, and 270°) were marked on top surfaces (A, B, C, and D) and the midpoints were marked on the outer surfaces. Specimens were placed on the holder, and measurements began after calibrating the device. On each line, measurements were taken twice for eight readings. Testing was carried out on all cylinders under saturated surface drying (SSD) conditions at 23°C±2°C.

A scanning electron microscope (SEM) with an energy-dispersive X-ray spectrometer was used to analyze the control and concrete mixture incorporated with agro waste.

3.3 Results and Discussion

3.3.1 Result of Argo-waste concrete

3.3.1.1 Slump Value

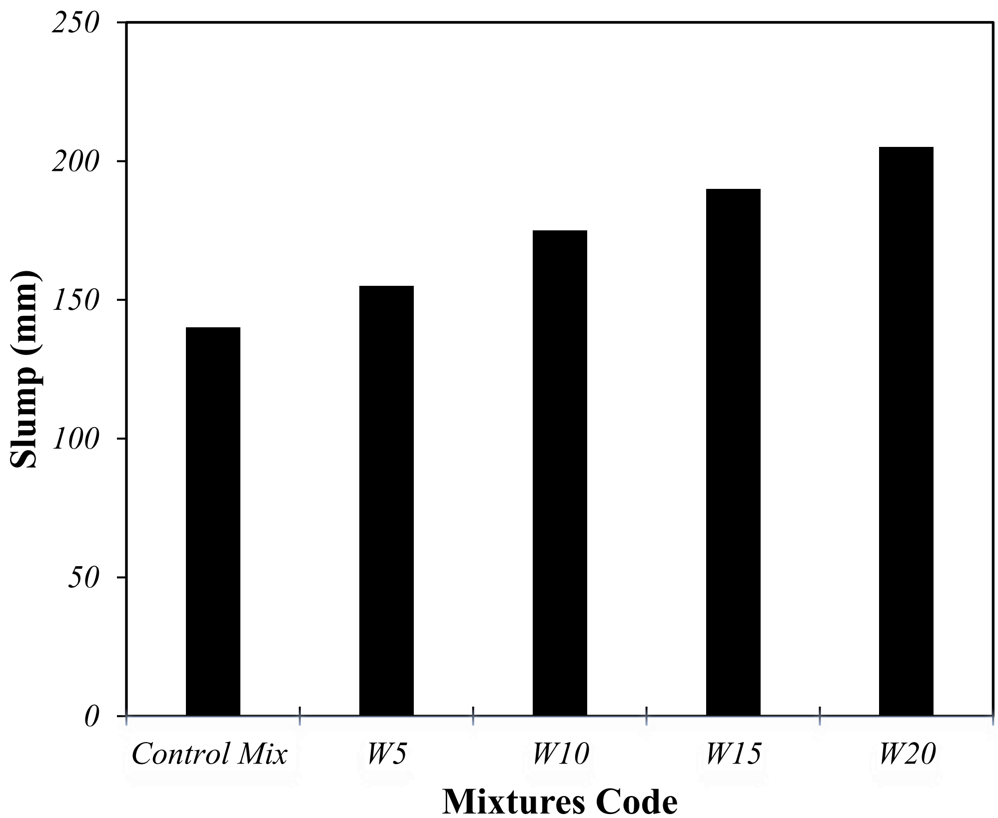


Figure 0.1: Result of Slump Value of agro-waste concrete mixtures.

Figure 0.1 shows the slump value for concrete mixtures with various agro-waste content. The water content of each mixture was adjusted to achieve typical flowability between 15 and 230 mm according to ASTM C143 [134]. The results of the slump in values ranged from 140 to 205 mm. According to Fig. 2, slump value increased with increasing agro-waste content. For instance, the slump value was 140 mm for the control mix, but when 20% of agro-waste was replaced as coarse aggregate, the slump value of 46% was improved. The water absorption capacity of agro-waste is greater than that of coarse aggregates. Hence, additional water was added to mixtures to maintain the flowability with the various agro-waste content [144]. Agro-waste is assumed to act as a sponge[145, 146]. Surface-saturated dry (SSD) agro-waste easily loses its water content during mixing, thereby slightly increasing the slump value of the mixture [147].

3.3.1.2 Density

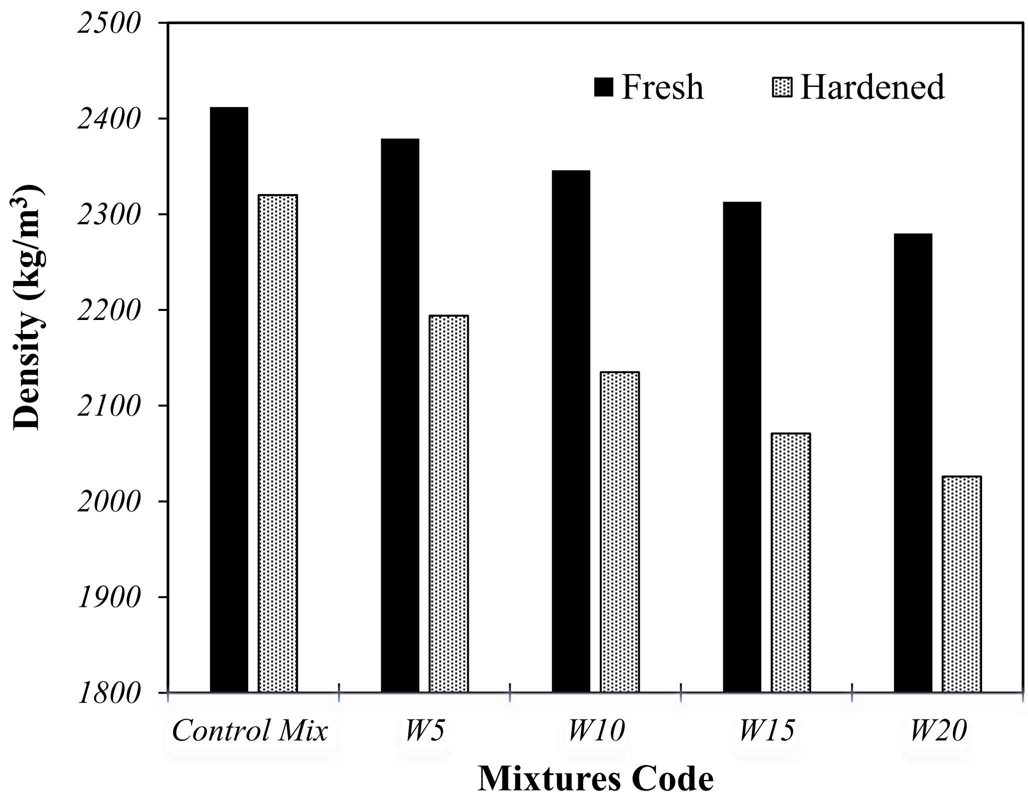


Figure 0.2: Result of Fresh and Hardened Density of agro-waste mixtures.

The density of fresh and hardened agro-waste concrete specimens was measured. The fresh and dry densities for the tested mixtures are summarized in **Figure *0.2*.** Fresh density for control and agro-waste concrete mixtures with different percentages of agro-waste up to 20 % ranged from 2280 kg/m^3 to 2412 kg/m^3. The higher the percentage of agro-waste, the lower the density. This is attributed to the low specific gravity of agro-waste compared to natural coarse aggregates [144]. According to Fig.3.2, the replacement of agro-waste up to 20% in the fresh density led to a about 6% reduction in density. For all tested mixtures, the dry density measured at age 28 days was lower than that of the fresh density. This is attributed to the specimens' water loss [148]. For instance, in the W10 specimen, specimens' fresh and hardened densities are 2346 kg/m^3 and 2131 $kg/m^{3,}$ respectively. Also, by increasing the agro-waste content, the dry density has significantly changed to the density of fresh concrete. This showed that the agro-waste keeps more water in a fresh state due to its porous texture [149].

3.3.1.3 Compressive Strength

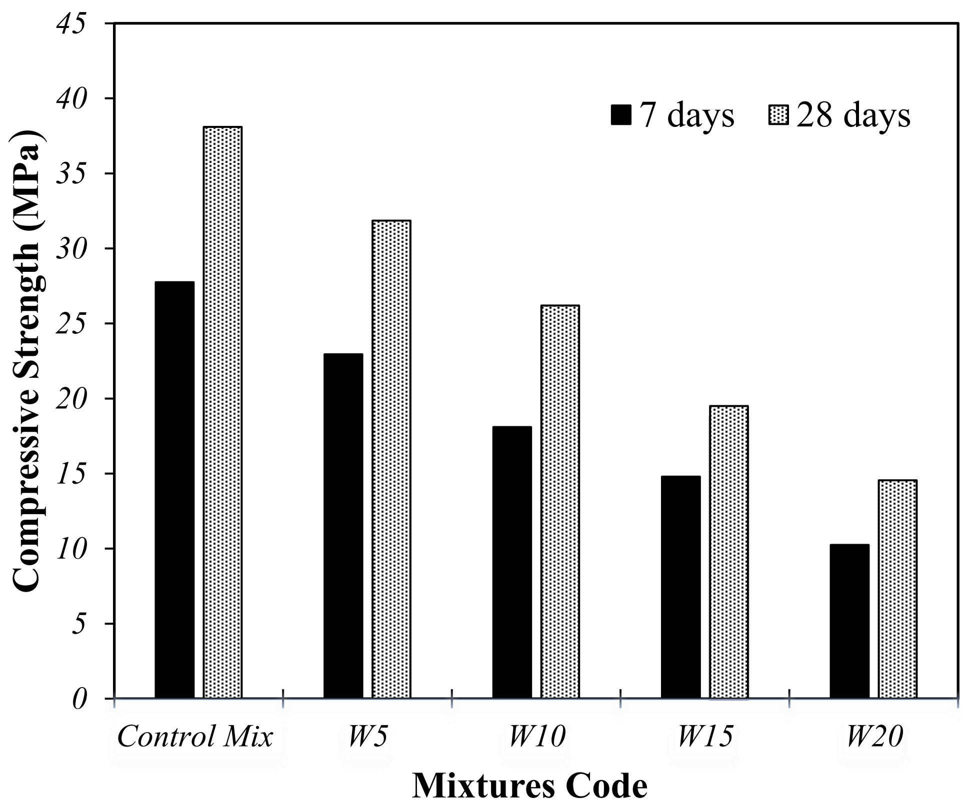


Figure 0.3: Result of Compressive Strength of agro-waste concrete.

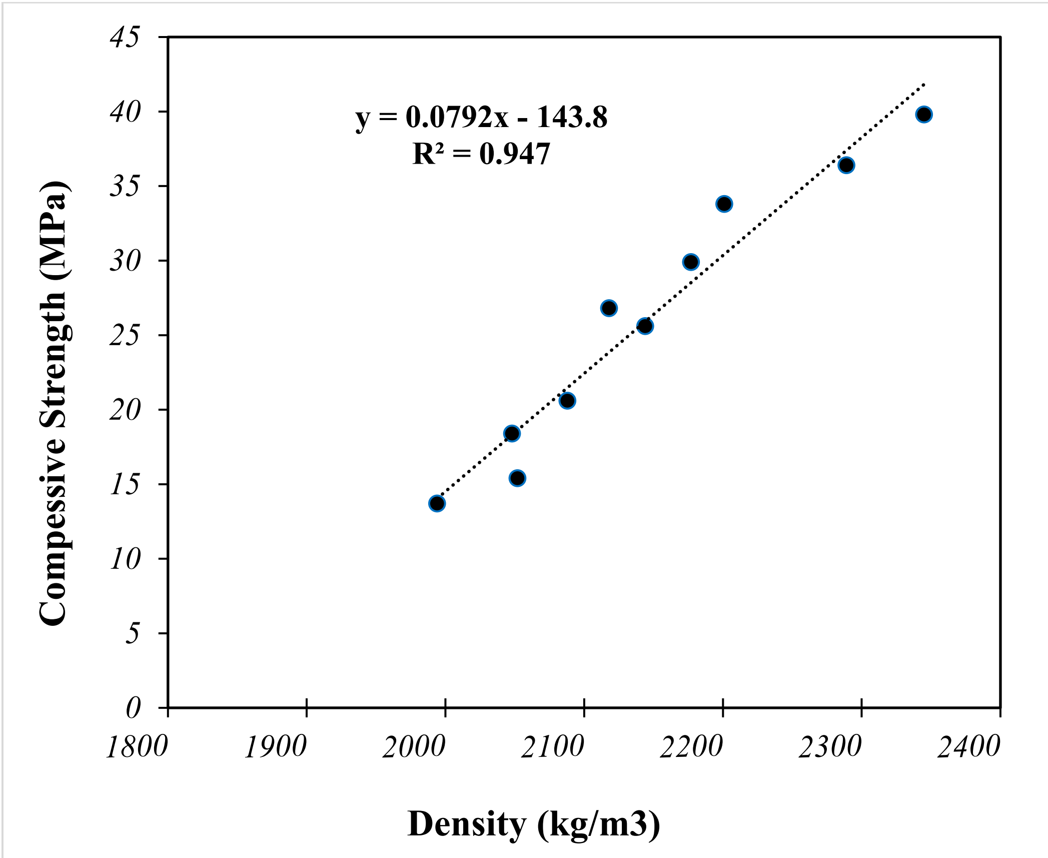


Figure 0.4: Relationship between Compressive Strength and Density of agro-waste concrete.

The compressive strength test is the most popular since it directly reflects the strength of the structure. **Figure *0.3*** shows the compressive strengths of various agro-concrete mixtures at 7 and 28 days. The compressive strength decreased as the agro-waste replacement to coarse aggregate increased. The higher the agro-waste content, the lower the compressive strength. For instance, mixtures incorporating 5% and 20% agro-waste exhibited about 21% and 63% lower seven days strength than control mixtures without agro-waste. Also, the compressive strength increased with time; however, the increase in strength was higher for mixtures with low agro-waste contents. For instance, the increase in strength for W20 was about 4 MPa compared to 12 MPa for the control concrete mixture. Increasing agro-waste content results in a higher surface area cornered by cement paste than natural aggregate. Hence, more cement paste is needed to adhere to them. As constant cement content was used, the bonding was inadequate.

Moreover, increasing the percentage of agro-waste reduced compressive strength [144]. This can be attributed to the characteristic of agro-waste, which is easily compressed with low stiffness.

Hence, cracks will form between the paste and the agro-waste, leading to a weaker bond. A reduction in the overall specific surface bonding of the concrete is attributed to air content within the concrete matrix, which acts as a stress concentration mechanism [145, 146]. Also, increasing the agro-waste content increases porosity and voids in the concrete. This is attributed to the shape and spongy characteristics of agro-waste, which cause it to keep water inside the agro-waste and then release the water that affects the hydration of concrete [145, 146]. Also, **Figure *0.4*** shows the relation between compressive strength and Density. It has been shown that the changes in the density were directly related to the compression strength achieved. Fig. 5 shows a strong correlation between the compressive strength of 28 days of age and density (R^2 = 0.947). In this regard, a higher density indicates a more compacted and denser microstructure, resulting in higher compressive strength [150].

3.3.1.4 Tensile Strength

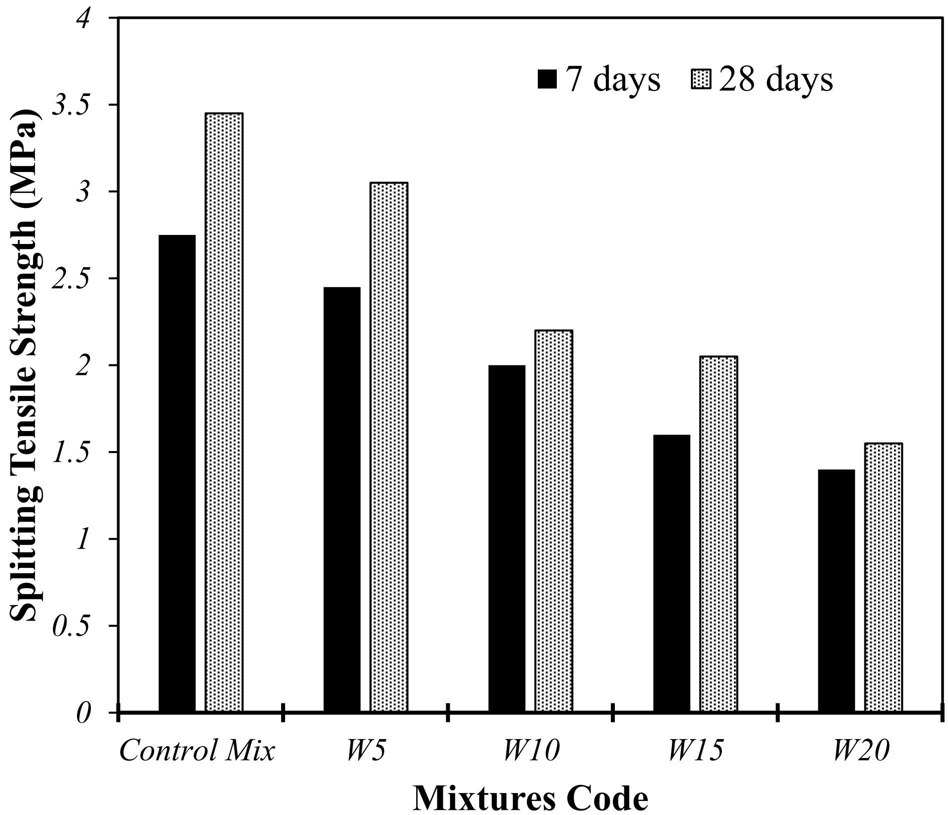


Figure 0.5: Result of Tensile Strength of agro-waste concrete.

The result of the tensile strength of agro-waste concrete at 7 and 28 days is shown in **Figure *0.5***. The result shows that increasing the amount of agro-waste as a replacement for natural aggregate reduced the tensile strength. For instance, the highest increase for tensile strength is for W15 between the 7 and 28 days, which is about 28 %. Also, the highest decrease was when agro-waste content increased from 10% to 15%. There is a direct relationship between the reduction in concrete's tensile strength and its components' strength. The low tensile strength of agro-waste concrete is due to agro-waste aggregate being porous and weaker microstructure compared to the natural coarse aggregate [151]. Secondly, the availability of high initial free water released from agro-waste due to the spongy characterization, causes channels and poor interfacial bonding between cement paste and aggregates [152, 153].

3.3.1.5 Flexural Strength

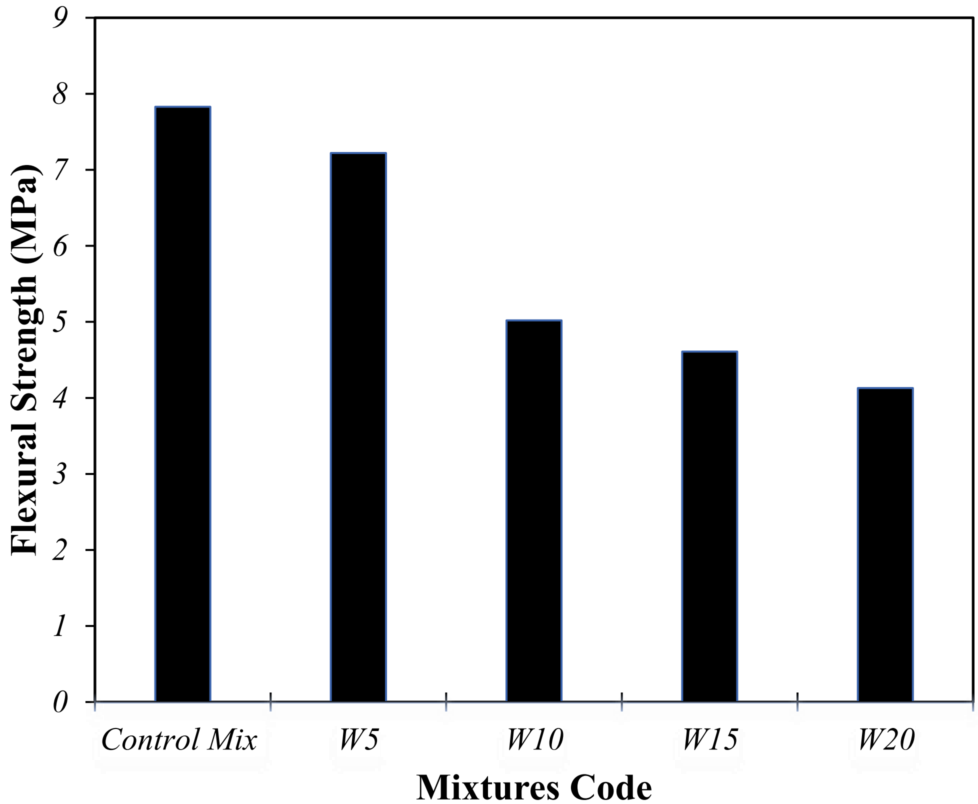


Figure 0.6: Result of Flexural Strength of agro-waste concrete.

The result of the flexural strength of agro-waste concrete at the age of 28 days is shown in **Figure *0.6***. The flexural strength decreased with increasing the percentage of replacement of agro-waste in the concrete, the same as the compressive and tensile strength. The flexural strength was reduced by approximately 52% when the agro-waste content increased up to 20%. Also, the most significant reduction was from 5% to 10% replacement of agro-waste, about 20%. The decrease in flexural strength can be explained by the higher number of voids resulting from the increased use of agro-waste [154]. This can be attributed to the fact that agro-waste tends to compress easily and has low stiffness [155]. Consequently, gaps form between the cement paste and the agro-waste, weakening their bond. The overall reduction in the effective surface bonding of the concrete is caused by the presence of air in the concrete matrix, which creates stress concentration points [145, 146].

3.3.1.6 Drying Shrinkage

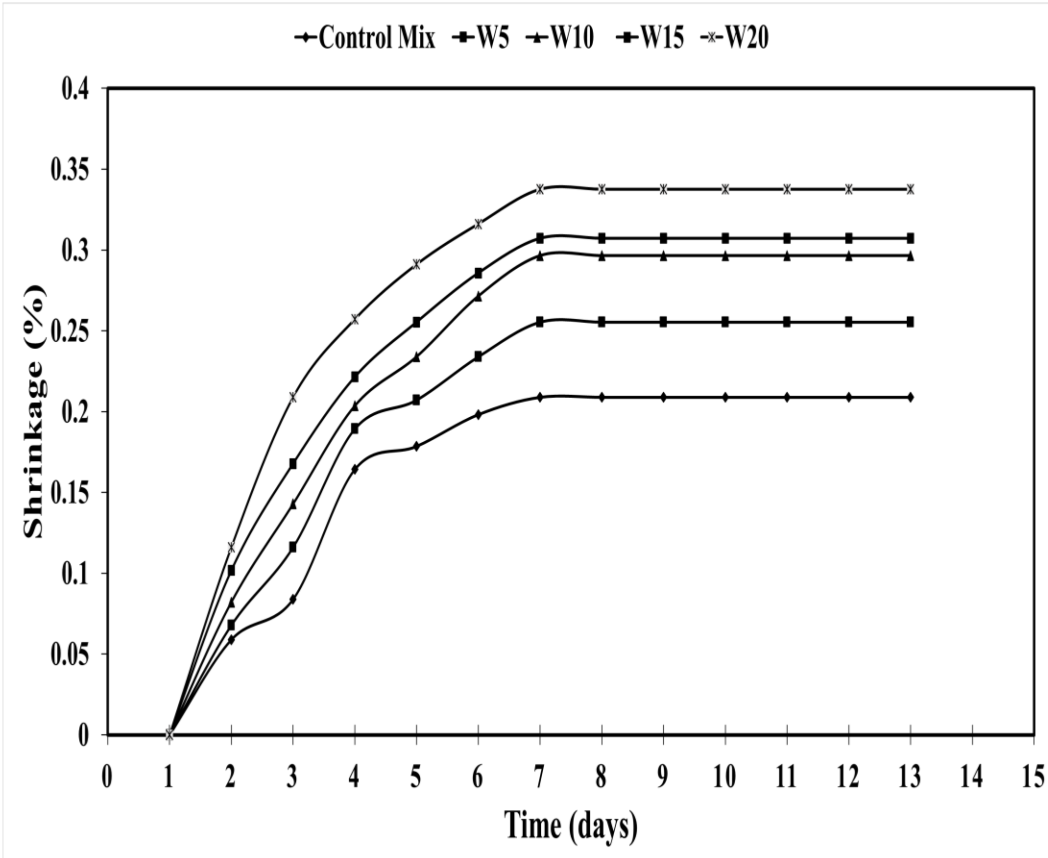


Figure 0.7: Result of dry shrinkage of agro-waste concrete.

Figure *0.7* shows the drying shrinkage for agro-waste mixtures over the investigation period. Results showed that shrinkage increased as the percentage of agro-waste increased. The control mixture specimen showed the lowest variation (0.21%). However, the W20 specimen had the highest shrinkage, about 0.36 %. Also, the most significant change in dry shrinkage was from 5% to 10% replacement of agro-waste as coarse aggregate. It occurred rapidly at the beginning of the shrinkage process for concrete incorporating agro-waste. After one week, it slowed down or became constant. This can be attributed to the high porosity of agro-waste aggregates. Agro-waste concrete generally contains more free water during the initial drying shrinkage stage. This way, higher replacement percentages of agro-waste in concrete resulted in more shrinkage. This can be attributed to an increase in porosity caused by the porosity of the agro-waste itself, that inside the matrix, and the increased connectivity of pores [147, 156]. The porosity and the interconnection of pores facilitate the evaporation of water, which accelerates the drying process and consequently increases shrinkage in the first days of the test [157].

3.3.1.7 Surface Resistivity

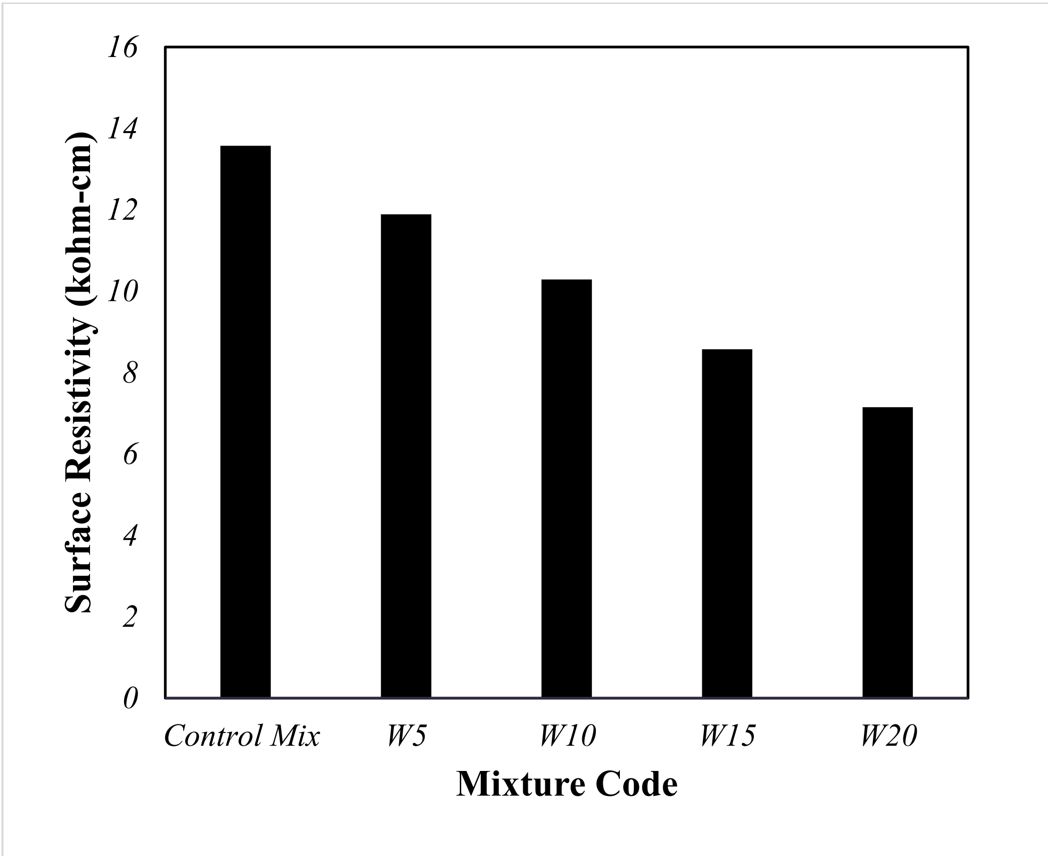


Figure 0.8: Result of surface resistivity of agro-waste concrete.

The results of the surface resistivity of agro-waste concrete at the age of 28 days are shown in **Figure *0.8***. Steel corrosion has a low chance because of the high surface resistivity of the concrete [158]. Internal structures of concrete, usually about pore size and pore solution properties, determine the resistivity. In general, increasing the percentage of agro-waste as a replacement for aggregate reduced the surface resistivity of concrete specimens. For instance, the highest decrease in surface resistivity is from 10% to 15% of agro-waste replacement, about a 17% decline.

In contrast, the lowest decrease in surface resistivity is from the control mix to 5%, about 13%. This can be attributed to both porosity characteristics of agro-waste and spongy structures having high impacts on concrete surface resistivity. The more agro-waste replaced natural coarse aggregate, the more porosities presented in concrete [147, 157].

3.3.1.8 Ultrasonic plus velocity (UPV)

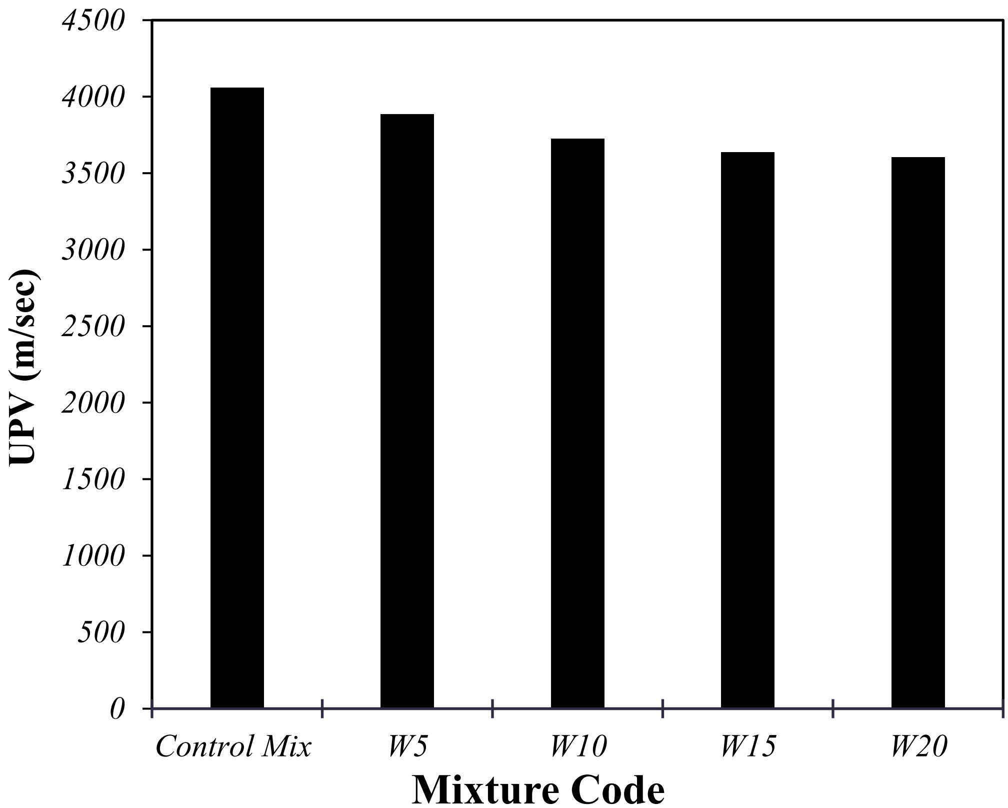


Figure 0.9: Result of UPV of agro-waste concrete.

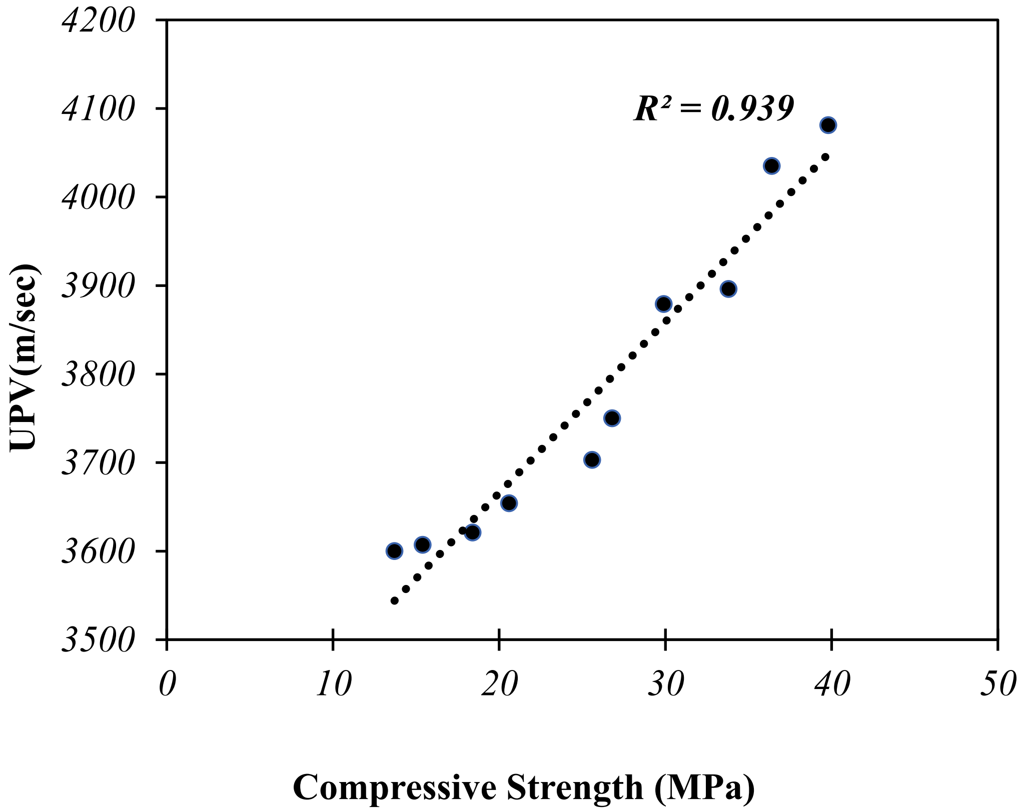


Figure 0.10: Relationship between UPV and compressive strength of agro-waste concrete.

In concrete specimens, a lower UPV value indicates the presence of voids. **Figure *0.9*** shows the results of the UPV test of agro-waste concrete at 28 days. The results illustrate that the wave velocity decreased by increasing the percentage of agro-waste in the concrete. For instance, the greatest changes occurred when 5% agro-waste was added to the mixture as a replacement for coarse aggregate. In continuation, the reduction percentage was decreased by increasing agro-waste content. So that this reduction reached 1 % when the agro-waste replacement increased from 15% to 20%. This can be attributed to the porosity in agro-waste, which will reduce the wave velocity. For instance, increasing the amount of agro-waste as a replacement from 5% to 20% caused a drop in wave velocity of about 11.2% [147, 157]. Also, **Figure *0.10*** shows the relation between the UPV and compressive strength. It has been shown that the changes in the UPV were directly related to the compression strength achieved. Fig. 10 shows a strong correlation between the compressive strength of 28 days of age and UPV values (R2 = 0.939). In this regard, a higher

UPV indicates a more compacted and denser microstructure, resulting in a stronger compressive strength [147].

3.3.1.9 Water absorption

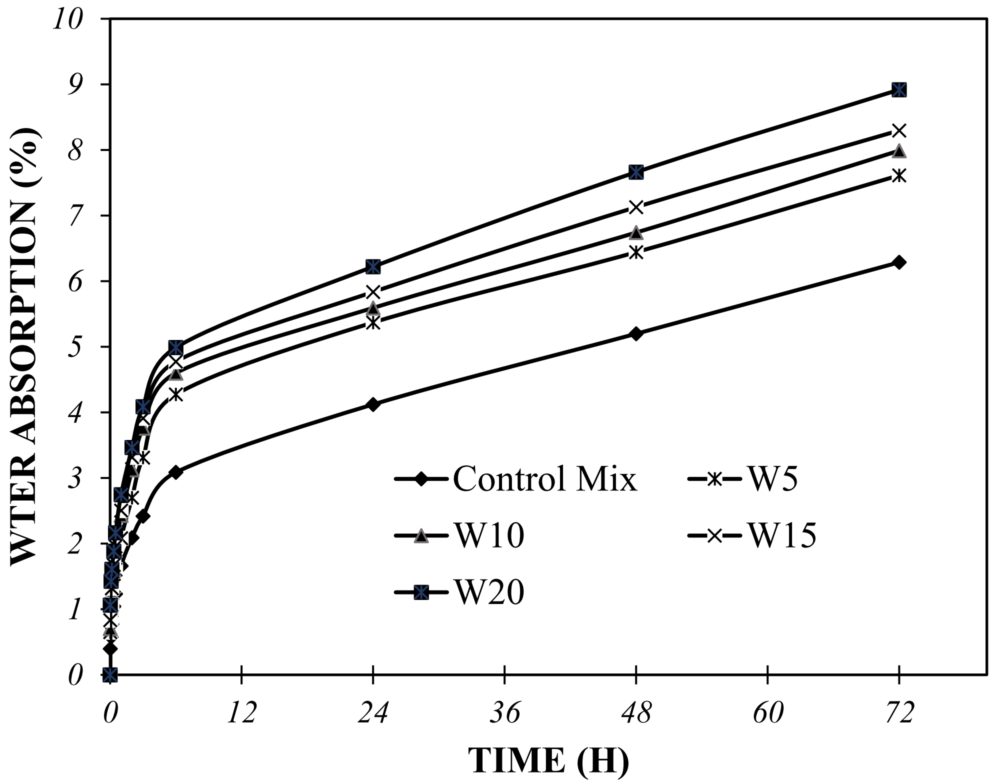


Figure 0.11: Result of water absorption of agro-waste concrete.

At 28 days, the initial water absorption test (1 minute) and the final water absorption test (72 hours) were carried out for all agro-waste mixtures. Based on the results presented in **Figure *0.11***.

, an increase in agro-waste amount up to 20% increased water absorption compared to the control mixtures. In the first 6 h of the water absorption test, the trend rose rapidly, but then the rise trend was a little bit slower. The high-water absorption rate of agro-waste particles as compared to natural coarse aggregates can be attributed to the high-water absorption rate of agro-waste particles [159]. Furthermore, with increasing quantities of agro-waste, the porosity of the concrete specimens increased as well. The reason for this can be attributed to the fact that agro-waste has a low volume-to-density ratio when compared to natural coarse aggregates [160, 161]. It is shown that agro-waste aggregate, which has a lighter weight than natural coarse aggregate, has a lower volume density than natural aggregate concrete, which comes from replacing the same volume of coarse aggregate with agro-waste. In addition, the highest changes of water absorption were from the control mix to W5.

3.3.2 Data Analyze of Agro-waste concrete

Based on the findings regarding the utilization of agro-waste in concrete tile production, it has been determined that the optimal replacement percentage for coarse aggregate with agro-waste is 5%. This choice is driven by the limitation imposed by the compressive strength requirement specified in ASTM C1731, which states that the mean compressive strength should be equal to or greater than 4000 psi (27.6 MPa), and no individual specimen should have a strength lower than 3600 psi (24.8 MPa). Consequently, only the mixture labeled as W5 was able to meet this limitation, exhibiting a compressive strength of 31.88 MPa at 28 days, while the mixture labeled as W10 had a strength of 26.2 MPa.

Furthermore, the increased percentage of agro-waste resulted in a decrease in the density of the concrete due to the lower specific gravity of agro-waste materials. Consequently, the W5 mixture displayed a lower density compared to the control mix which can be more applicable in the construction industry. Additionally, the inclusion of higher proportions of agro-waste in the concrete led to increased shrinkage. Moreover, the surface resistivity of the concrete specimens decreased as the percentage of agro-waste replacement increased. Furthermore, an increase in agro-waste content resulted in a reduction in the wave velocity of the concrete. In comparison to the control mixture, the specimens with higher agro-waste content exhibited greater water absorption.

3.3.3 Results of Agro-waste Concrete tile

3.3.3.1 Density

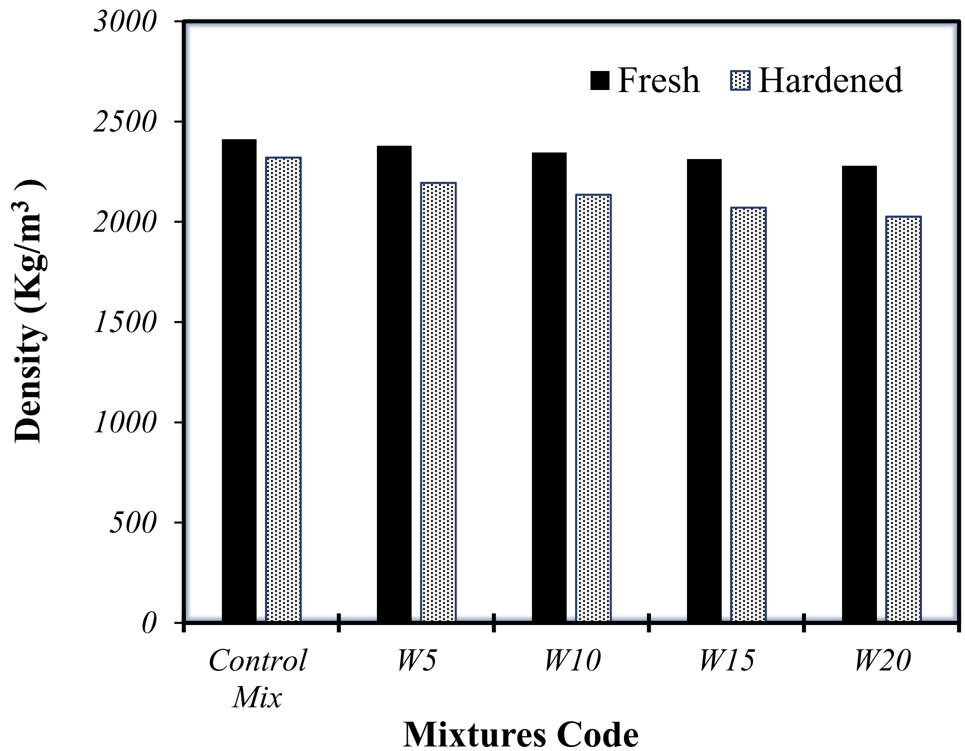


Figure 0.12: Result of Density of Agro-waste concrete tile.

The density of fresh and hardened agro-waste concrete tile was measured. According to **Figure *0.12*** , the fresh and dry densities of the concrete tile mixtures are summarized. There was a wide range of fresh density between 2280 kg/m3 and 2412 kg/m3 for control and agro-waste concrete tile mixtures with different percentages of agro-waste up to 20%. A higher percentage of agro-waste results in a lower density. It is believed that this is due to agro-waste having a lower specific gravity than natural coarse aggregates [144]. Agro-waste concrete also has higher air voids due to weaker bonds than natural aggregates and cement paste. At age 28 days, the hardened density of all concrete tile mixtures was lower than the fresh density. There was a wide range of dry density between 2258 kg/m3 and 2020 kg/m3. For instance, the hardened density of W10 was 2145 kg/m3. It is believed that this is due to the loss of water from the concrete tile. In addition, the dry density of the concrete has significantly changed as a result of increasing the agro-waste content. The results showed that agro-waste keeps more fresh water. The reason for this is the presence of a porous texture. These findings indicate that lighter-weight agro-waste concrete tile can be achieved through the use of a higher percentage of agro-waste [43].

3.3.3.2 Flexural Strength

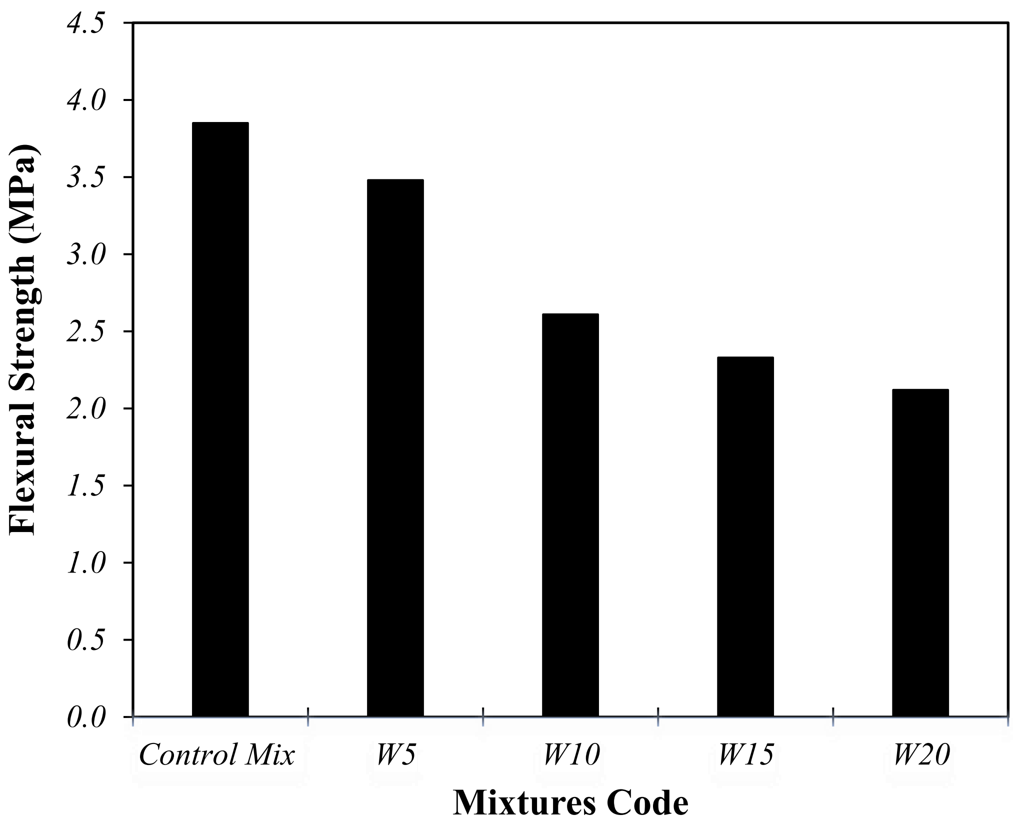


Figure 0.13: Result of Flexural Strength of Agro-waste concrete tile.

According to the findings presented in **Figure *0.13*** , the flexural strength of agro-waste concrete tiles decreased after 28 days of curing. The decrease in flexural strength was observed with an increase in the percentage of agro-waste replacement in the concrete tiles. Notably, the most significant reduction occurred within the range of 5% to 10% replacement which is approximately 27 %. For instance, the flexural strength of W10 is about 2.5 MPa. However, the flexural strength of W5 is about 3.4 MPa. The lowest strength is for W20 which is about 2.1 MPa. This decline in flexural strength can be attributed to the higher number of voids that emerge as the agro-waste content increases. The easy compressibility of agro-waste when in a wet state leads to a weak bond between the concrete paste and the agro-waste, resulting in the formation of cracks under loading conditions. Moreover, it has been demonstrated that the presence of air within the concrete matrix reduces the specific surface bonding of the concrete, as stress gets concentrated within the matrix [144-146].

3.3.3.3 Water Absorption

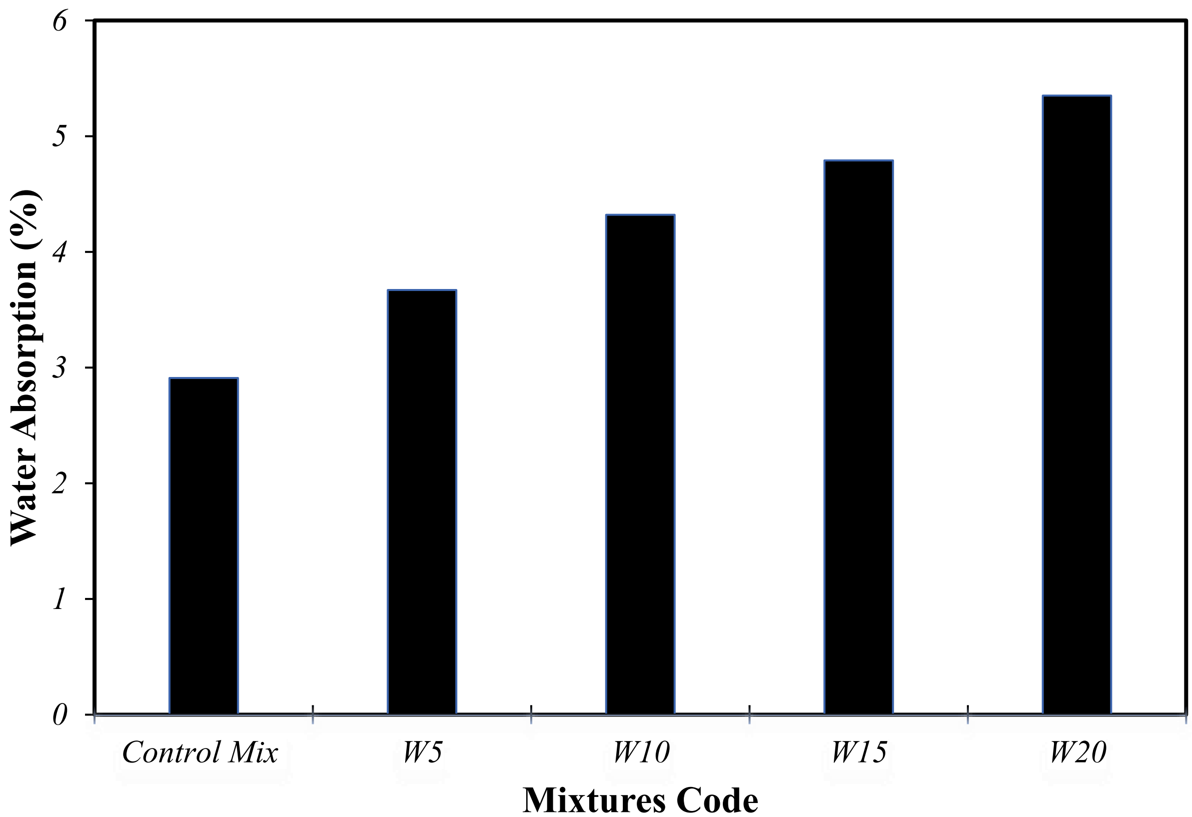


Figure 0.14: Result of Water Absorption of Agro-waste concrete tile.

Water absorption tests were conducted after 28 days on all agro-waste concrete tile mixtures. **Figure *0.14*** shows that an increase in agro-waste content of up to 20% increased the absorption of water as compared to the control mixtures. For instance, the water absorption of W5 is about 3.7 % but for W15 is about 5.7%. This can be attributed to agro-waste particles absorbing more water than natural coarse aggregates because of their high-water absorption rate [159]. Moreover, as the amount of agro-waste increased, the porosity of the concrete tile specimens increased as well. As a result, the volume-to-density ratio of agro-waste is lower than that of natural coarse aggregates[162, 163]. As a result of replacing the same volume of coarse aggregate with agro-waste, agro-waste aggregates have a lower volume density than natural coarse aggregate concrete.

3.4 Conclusion

Based on the mentioned results and discussion, it can be conclusively stated that the utilization of this agro-waste in the production of concrete tiles is a feasible approach. The resulting concrete tiles exhibit acceptable compressive strength levels while also demonstrating lower density compared to traditional concrete. It is evident from the experimental findings that the compressive strength of the concrete tiles decreases significantly as the content of agro-waste increases. The main contributing factor to this reduction in strength is attributed to the porous nature of the agro-waste, which weakens the overall structural integrity of the concrete. However, it should be noted that replacing 5% of the coarse aggregate with agro-waste is deemed acceptable in order to meet the specified limits for compressive strength in concrete tiles. In conclusion, the research findings suggest that incorporating agro-waste into concrete tile production can yield satisfactory results in terms of compressive strength, while also offering the advantage of lower density when compared to conventional concrete.

CHAPTER 4: USING AGRO-WASTE IN PRODUCTION OF ALKLAI-ACTIVATED PARTICLE BOARD

The increasing scarcity of virgin natural resources and the need for sustainable waste management in densely populated urban areas have led to a greater emphasis on developing new technologies for recycling waste materials. One promising approach involves recovering agricultural waste from construction projects and transforming it into secondary products, reducing the reliance on new resources and lessening the environmental impact in line with industrial ecology principles. A valuable outcome of this effort was the creation of an alkali-activated particleboard, which was produced by utilizing leftover materials from agro-waste processing, combined with slag as a binding agent. In this study, the effects of accelerated aging on the performance of alkali-activated agro-waste particleboards were investigated. The accelerated aging conditions considered simulated natural aging phenomena. Repeated wetting–drying and freezing–thawing cycles led to increased water absorption and thickness sweliing. However, the density of alkali-activated agro-waste particle board decreased. Also. the flexural strength of alkali-activated particle board. Also. Ceuring condition had negative effect on the thermal performance of particle board specimens.

4.1 Introduction

Alkali-activated concrete provides a sustainable and innovative alternative to traditional Portland cement-based concrete [164]. Alkali-activated concrete offers several advantages. It reduces carbon dioxide emissions associated with cement production by utilizing industrial by-products like fly ash, which would otherwise be disposed of as waste [165]. This makes it an environmentally friendly choice. Additionally, alkali-activated concrete demonstrates excellent durability, resistance to chemical attack, and reduced shrinkage compared to traditional concrete [166]. The most important characteristic of alkali-activated concrete that makes it distinct from cement-based concrete is to provide a sustainable, durable, and high-performance material for a wide range of construction applications, contributing to the development of more environmentally conscious and long-lasting structures [167]. In this regard, alkali-Activated concrete is used for different applications. One of these applications is an alkali-activated particle board.

Alkali-activated particle board is a new product in the construction industry, bringing a high level of durability and resistance to traditional particle boards [168]. This type of board is treated with alkali substances that enhance its performance characteristics, most notably its resilience against moisture and potential for higher mechanical strength [169]. The process involves activating binder materials within the agro-waste composite using alkaline solutions, creating chemical reactions that form durable bonds within the structure [170]. As a result, alkali-activated particle boards offer improved environmental stability over cement-bonded particle boards, showing greater resistance to water absorption and less susceptibility to swelling or warping [168]. They also present an eco-friendlier alternative due to their use of low-energy processes and potential for incorporating recycled materials [171].

Cement-bonded and alkali-activated particleboard have been minorly studied in engineered wood composites. Researchers have focused on investigating the mechanical properties, durability, and manufacturing processes of these materials [172-175]. Several studies have shown that Cement-bonded particleboard exhibits improved strength, dimensional stability, and resistance to moisture compared to traditional particleboard, making it suitable for various structural applications [173, 174, 176, 177]. The use of alkali-activated binders in alkali-activated particleboard has garnered attention due to their potential for enhancing performance and sustainability [168, 178]. Researchers have explored different types of alkali-activated binders derived from industrial by-products and waste materials, evaluating their effects on the mechanical and physical properties of alkali-activated particleboard [168]. Furthermore, efforts have been made to optimize manufacturing techniques, such as particle size distribution and mixing parameters, to enhance the overall quality and performance of both Cement-bonded particleboard and alkali-activated particleboard [168, 172]. These literature findings highlight the potential of Cement-bonded particleboard and alkali-activated particleboard as viable alternatives to conventional particleboard, paving the way for further advancements and practical applications in the construction industry.

Although there has been significant research on particleboard, there are still notable gaps in the existing studies. One of the main areas that require further exploration is the long-term durability and performance of these materials under various environmental conditions, including exposure to moisture, temperature fluctuations, and external stresses [179]. Additionally, while the mechanical properties of particle boards have been investigated, there is a need for more comprehensive studies that consider the effects of different parameters, such as particle size, binder composition, and manufacturing processes, on the overall performance of these engineered wood composites [174]. Furthermore, there is limited research on the practical implementation of particle boards in real-world applications, including their structural behavior, fire resistance, and compatibility with other building materials [180, 181]. Addressing these gaps would contribute to a deeper understanding of the potential limitations and opportunities associated with the use of cement-bonded and alkali-activated particleboard in various construction industries [182].

The present study evaluates the mechanical properties and durability of using agro-waste in the production of alkali-activated particle boards. It investigates the effects of different curing conditions on the resulting board's performance, including its strength, thickness swelling, and resistance to moisture and decay. By utilizing agro-waste, the research aims to promote sustainable practices in both the construction and agricultural sectors, reducing waste and utilizing renewable resources. The ultimate objective is to develop an applicable product that meets the technical requirements of construction applications while providing economic and environmental benefits to the agricultural industry. The findings of this study will contribute to advancing the understanding of alkali-activated particle board and its potential as a viable and sustainable alternative in the field of engineered agro-waste composites.

4.2 Experimental Program

4.2.1 Materials

Granulated blast furnace slag (hereafter referred to as slag) consists in all zero-cement particle board mixtures were also made from, which had an average particle size of 14.5 µm, according to ASTM C618 [183]. The physical and chemical properties of the Slag are presented in ***Table 4.1***.The dry-powder activator, Meta Na_2SiO_3 with a 10% ratio, was mutually utilized to activate the zero-cement particle board mixtures. The used Na_2SiO_3 had a density of 1.09 g/cm^3 and a molar ratio of 1.0. The Chemical and physical properties of Anhydrous sodium meta-silicate are shown in **Table *4.2***. A water-to-binder (w/b) ratio of 0.40 was determined based on the mass of the binder. An agro-waste commercially known as Topimamerboor is used to produce zero cement-bonded particle boards using 1:2, 1:3, and 1:4 ratios. Figure (1) shows the used agro-waste aggregate in this study is shown in the ***Figure 4.1***.

Table 4.1: Chemical compositions of used slag.

Items	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3	MgO	K_2O	Na_2O	TiO_2	M_nO_2
(%)	36.5	10.2	37.6	0.5	3.1	11.8	0.4	0.3	1.0	0.4

Table 4.2: Chemical and physical properties of Anhydrous sodium metasilicate.

Property	W_t % Na_2O	W_t % SiO_2	W_t % H_2O	Density (g/cm^3)	Particle Size	Melting Point (°C)	The heat of solution (kJ/mol)
Typical Data	50.5	46.2	<3	1.09	93% in 20 to 65 mesh	1088	−31.7

Figure 4.1: Agro-waste is used in this study (the commercial name is Topimamerboor).

4.2.2 Mixture procedure and properties

In this study, three mixed designs were cast, as shown in **Table *4.3***. The agro-waste was submerged in water for 24 hours to reduce its high-water absorption (saturation level) and then compressed with a hydraulic jack for 4 MPa pressure prior to mixing. Afterward, the agro-waste was blended with other ingredients according to ASTM C305 [183] for 5 minutes. Due to the wet condition of the agro wastes, water-to-binder ratios were set at approximately 0.4. The specimens were cast into molds and rested for 24 hours at a temperature and relative humidity of 23 ± 2 °C and 50 ± 3 %, respectively. To prevent the elastic expansion of agro-wastes for the first 24 hours, the molds were clipped on top and bottom from two sides.

Table 4.3: Mix properties of zero-cement particle boards.

Mix Code	W/B	Meta silicate (%)	Agro waste: Bider ratio	agro waste (g)	Slag (g)	Water (g)
M1	0.4	10	1:2	100	200	40
M2	0.4	10	1:3	100	300	40
M3	0.4	10	1:4	100	400	40

4.2.3 Curing condition

4.2.3.1 Normal curing condition

Following the pressing process, the compressed material was released and then the boards were taken out of the mold. In this study, there are 3 curing conditions: ambient conditions, wetting and drying cycles, and freezing and thawing cycles. First, to maintain stable environmental conditions and prevent water loss, the boards were then covered with a closed box and kept in the laboratory for 28 days.

4.2.3.2 Wetting and drying curing condition

25 wetting and drying cycles were conducted on cylindrical specimens by alternating temperature and relative humidity after 28 days of curing followed according to ASTM C1185 [183]. By repeating the wetting and drying cycles, we were able to simulate the rain-heat cycles that occur in natural weathering. Due to this aging condition, some key chemical and physical mechanisms of deterioration are stimulated. Moreover, these conditions lead to an increase in the alkaline pore water attack on wood particles, as well as the migration (through dissolution and re-precipitation) of some alkali-activated hydration products into the wood fiber cores and their interfaces.

4.2.3.3 Freezing and thawing curing condition

The freezing and thawing cycle of specimens, temperature, and humidity were adjusted by a refrigerator. 25 freezing and thawing cycles were considered for all specimens in this investigation. zero-cement particle boards were considered for a further 1 freezing and thawing cycle. Due to the discontinuation of freezing and thawing test standards for stabilized soils, the ASTM C666 [183]" ASTM C666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing" temperature cycles were evaluated. One freezing and thawing cycle consisted of freezing for 16 hours at -20°C (23°F) and thawing for 8 hours at +20°C (86°F).

4.2.4 Tests

4.2.4.1 Density

In accordance with BS EN 12390–7:2019, the density of the samples was determined. Two specimens were cut out and their weights recorded in relation to their volume. The bulk densities of the samples were calculated using equation (1).

$Density\ (g/cm^3) = W_a / V_a$

Where;

W_a = *Air Dried Weight;* V_a = *Air Dried Volume*

4.2.4.2 Water absorption

Water absorption was determined according to BS 1881–122:2011. Initial weight was recorded using a weighing balance for two specimen samples cut from the board. The specimens were then weighed after being immersed in water for 2 hours and for 24 hours (at room temperature), and the weight of each specimen was recorded as the final weight. Equation (2) was used to determine the percentage of water absorbed by each specimen.

$Water\ Absorption\ (\%) = \frac{Wf - Wi}{Wi} * 100$

Where;

W_f = *Final Weight of the Board;* W_i = *initial Weight of the Board*

4.2.4.3 Thickness swelling

Thickness swelling was determined according to ASTM standard D1037-03. Using a Vernier caliper, the initial thickness of the samples was recorded as. After being immersed in water for 2 hours and 24 hours, the samples were measured in terms of their final thickness. Equation (3) was used for calculating the water absorption of each sample to obtain the percentage absorbed.

$Thickness\ Swelling\ (\%) = \frac{Tf - Ti}{Ti} * 100$

Where;

T_f = Final Thickness of the Board; W_i = initial Thickness of the Board

4.2.4.4 Thermal performance

This test focused on assessing the thermal performance of concrete when exposed to radiant heat from a heat and cold cycle. To conduct this non-destructive test, we utilized suitable specimens made from alkali-activated agro-waste particle boards. The goal was to simulate the heat exposure that concrete surfaces might experience, with real-world conditions indicating a surface temperature of approximately 30°C. Our aim was to understand how heat penetrates concrete, as it can significantly impact indoor temperatures in buildings.

To execute this experiment, we employed a device equipped with an environmental chamber designed for radiating heat. Each test involved using particle board specimens measuring 150 × 150 × 10 mm, a choice made to save time and minimize potential errors. We utilized the FLIR E6 thermal camera, known for its ability to capture high-resolution images with a 160 * 120 IR resolution. The camera's advanced lens offered high sensitivity, ensuring precise temperature measurements. The heating and cooling cycle details are depicted in the accompanying ***Figure 4.2***.

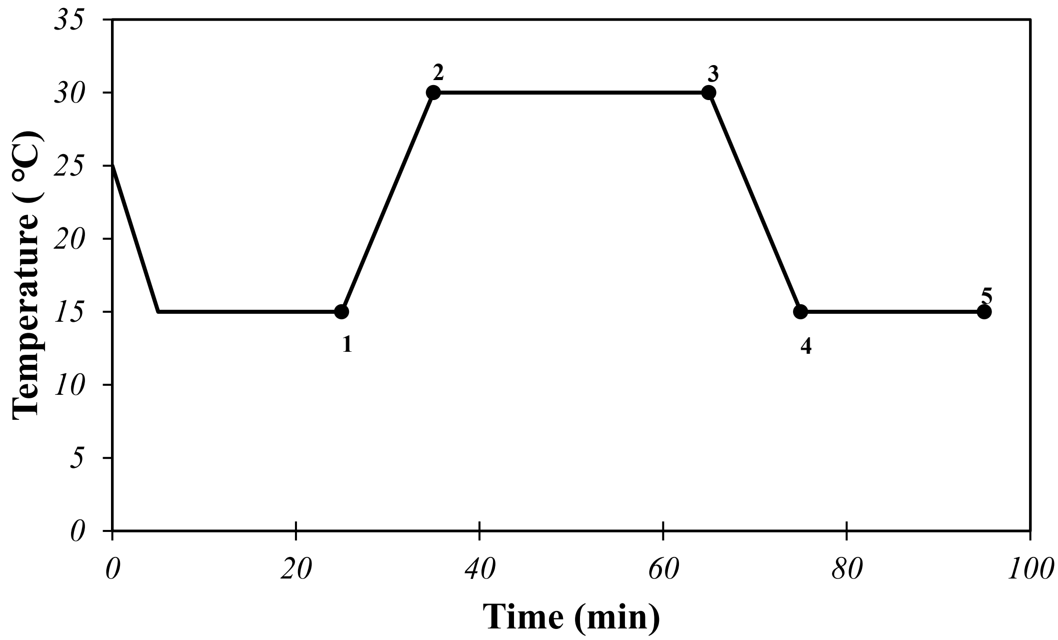


Figure 4.2: Thermal performance heating and cooling cycle and 5 point of monitoring.

4.2.4.5 Flexural Strength

The flexural strength of the zero-cement particle board was determined based on ASTM C140 [184]. The particle boards were placed on their flat onto a flexural beam apparatus and subjected to a three-point loading setup, with the maximum load being recorded. The load was gradually applied until the particle boards failed and a load versus deflection curve was plotted. The force that caused the particle board to fail was identified, and the wet transverse strength was computed. The pattern and spread of cracks were observed.

4.2.4.6 SEM (Scanning Electron Microscope) and XRD

A scanning electron microscope (SEM) equipped with an energy-dispersive X-ray spectrometer was used to analyze the reference and concrete incorporation with agro waste. Secondary electron imaging (SEI) from typical specimens mounted on double-sided carbon tape and sputter-coated with Au was used to study the influence of agro-waste addition on the microstructural properties of the concrete.

4.3 Result and Discussion

4.3.1 Density

Figure ***4.3*** shows the result of alkali-activated particle board density. The results show that specimen 25WD200 had the least density of 1052 kg/m^3 and specimen NC400 had the highest density of 1691 Kg/m^3. According to IS 14276, the suggested lower limit for density is 1250 kg/m^3, while JIS.A.5908 advocates for a minimum density value of 800 kg/m^3. All particle boards manufactured adhered to these minimum standards as recommended. Fig (1) shows that particle board density increased when the slag content increased. However, the density of particle boards decreased when the specimens were cured in the freezing and thawing cycles and dry and wet cycles. Also, the results show the density of particle boards decreased when the number of cycles increased. For instance, the density of 10FT300 was 1486 Kg/m^3 but 24FT300 was 1310 Kg/m^3. Also, the specimens under wet and dry cycle curing had lower density in comparison with freezing and thawing cycles curing so that 25FT400 in comparison with 25WD400 had 8.5 % less density. This is attributed to the change in the thickness of specimens of particle boards when were cured in the freezing and thawing cycles or wet and dry cycles.

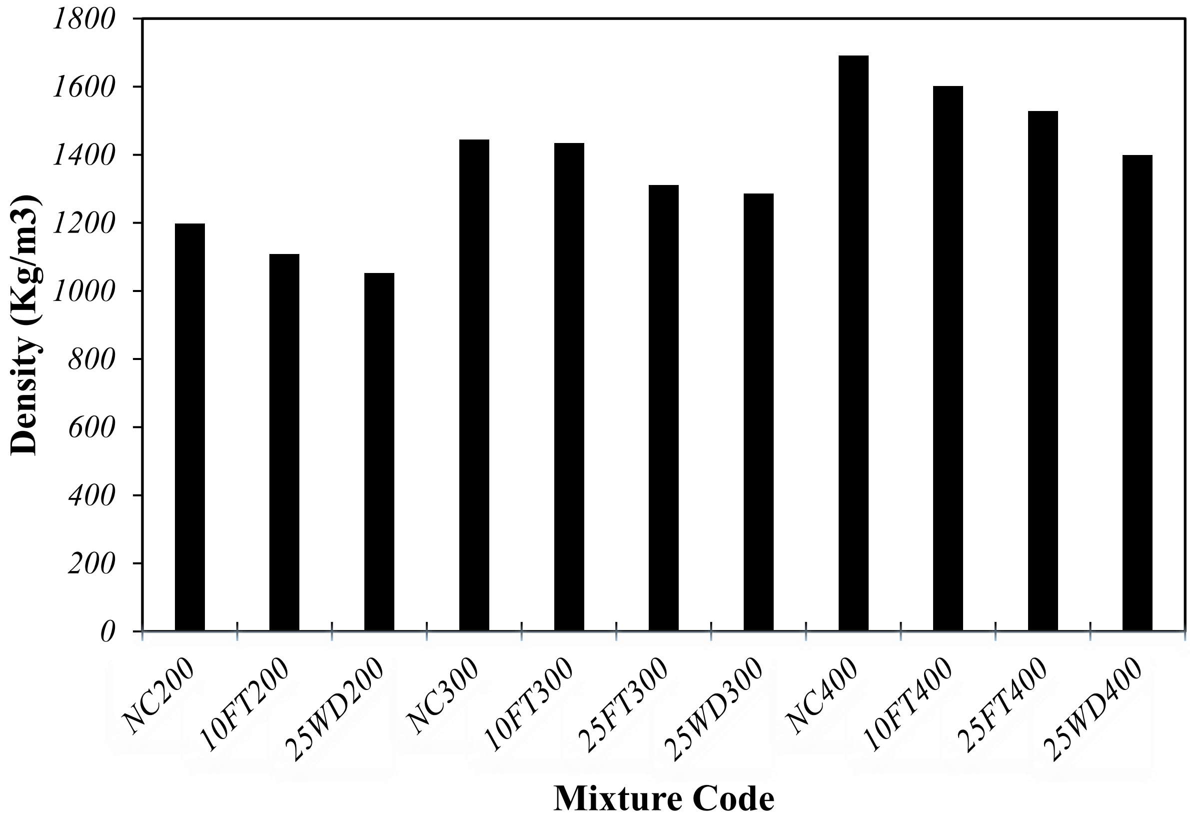


Figure 4.3: The result of the density of particle board with different slag content and curing condition.

4.3.2 Thickness swelling

The thickness swelling of alkali-activated particle board results is displayed in the submersion in water after 2 and 24 h in **Figure** ***4.4***. According to the guidelines set by the American National Standards Institute, the maximum allowable thickness swelling is 8%. As a result, all the tested specimens met the requirement for thickness swelling. The results show that 25FT200 and NC200 have the most significant changes in thickness which are 5.12% and 4.65% in 24 h submersion in the water, respectively. However, the lowest changes in thickness are for NC400 which is 2.17% in 2 h submersion in the water. This can be attributed to the ratio of agro-waste to slag that shows increasing the content of slag leads to a decrease in thickness swelling. The widely accepted fact is that when the ratio of agro-waste to slag in particle boards rises, it leads to a notable increase in thickness swelling, subsequently resulting in a decline in the boards' dimensional stability. In addition, the thickness swelling was increased when the particle boards are cured in freezing and thawing or drying and wetting conditions. For instance, it can be shown that specimens 25FT300 and 25WD300 have more changes in comparison with NC300 which are 4.11% or 4.20% in 24h water submersion, respectively. Also, it can be shown that curing in the drying and wetting condition has more effect than freezing and thawing curing conditions. For instance, specimen 25WD400 had more changes in thickness swelling in comparison with 25FT400. This can be attributed to the increase in the amount of pore when the specimens are cured in these conditions.

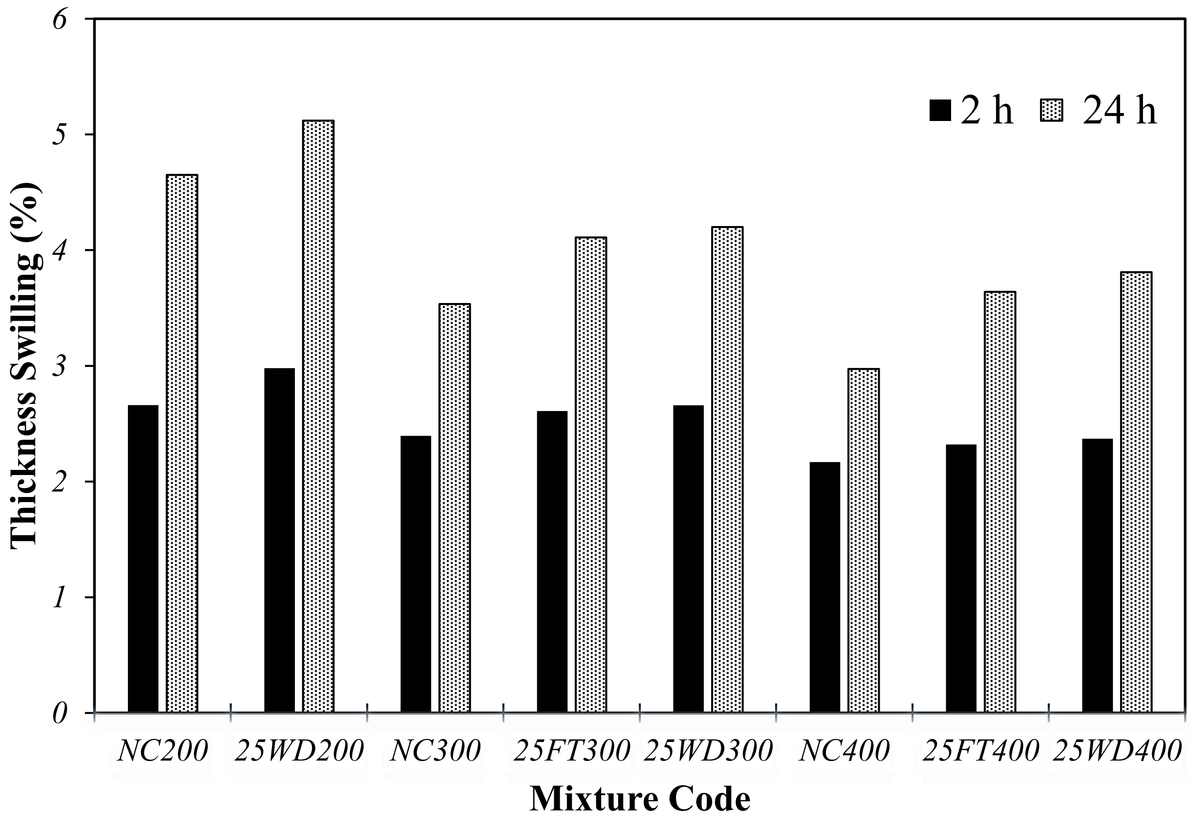


Figure 4.4: The result of the thickness swelling of particle board with different slag content and curing condition.

4.3.3 Water absorption

The result of water absorption of alkali-activated agro-waste particle boards is shown in **Figure *4.5***. The specimens were tested after being immersed in water for 2 and for 24 hours. The results show that the highest water absorption is for 24WD200 which is about 46.88% in 24 h water immersion. However, the lowest water absorption is for NC400 which is about 28.8 %. Also, increasing the content of slag in the particle board specimens can lead to decreasing in water absorption. For instance, NC200 which is about 29.44% in 2 h water immersion. However, the lowest water absorption is for NC400 which is about 24.35 %. This can be attributed to the ratio of agro-waste to slag, when the ratio of agro-waste to slag increased, the water absorption of the specimen of particle boards decreased due to a higher reaction of agro-waste particles with slag. It is obvious, as shown in Fig. (3), that the particle board specimens had higher water absorption when immersed for 24 h compared to those immersed for 2 h. In addition, the specimens which are cured in drying and wetting or freezing and thawing conditions had higher water absorption in comparison with normal curing conditions. For instance, the 25WD400 had more water absorption than NC400. Also, the water absorption of the particle board specimens follows the order from low to high as follows: normal curing condition, wetting and drying cycle, and freezing and thawing cycle. This can be attributed to the reduction in the degree of polymerization.

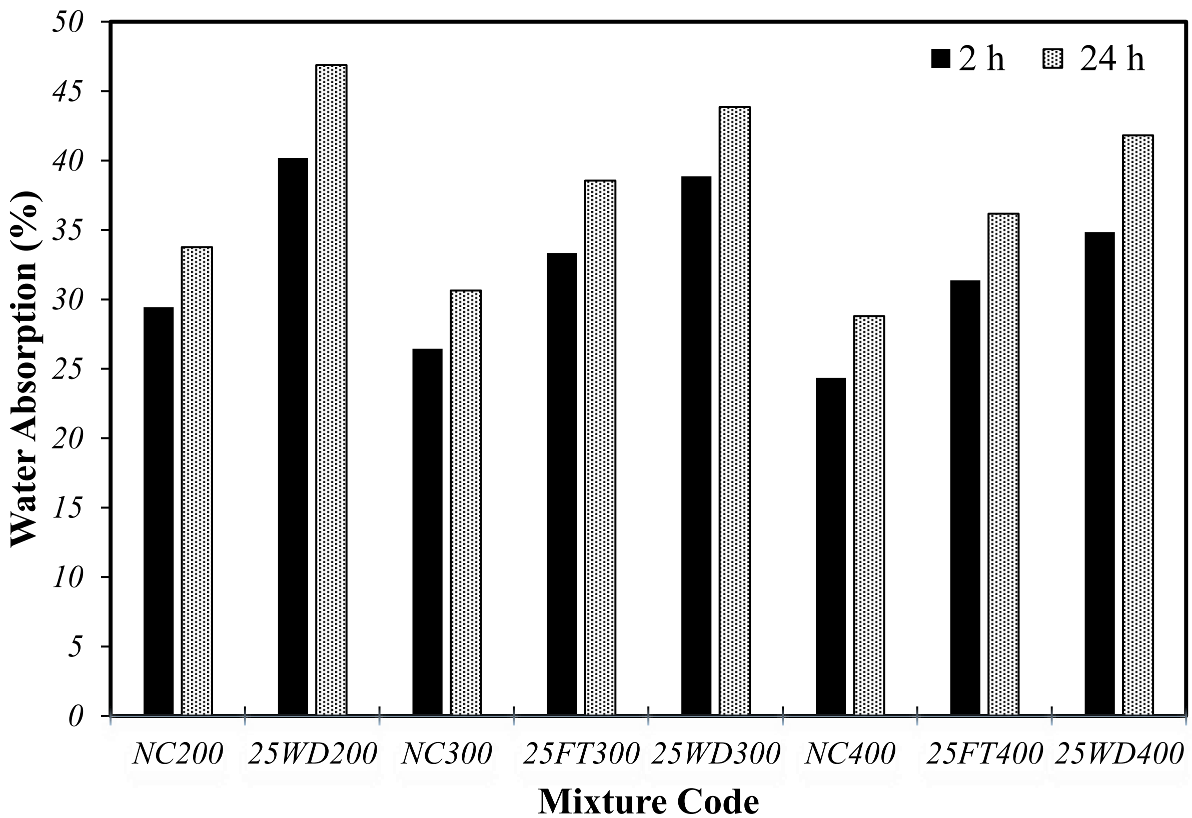


Figure 4.5: The result of the water absorption of particle board with different slag content and curing condition.

4.3.4 Failure mode

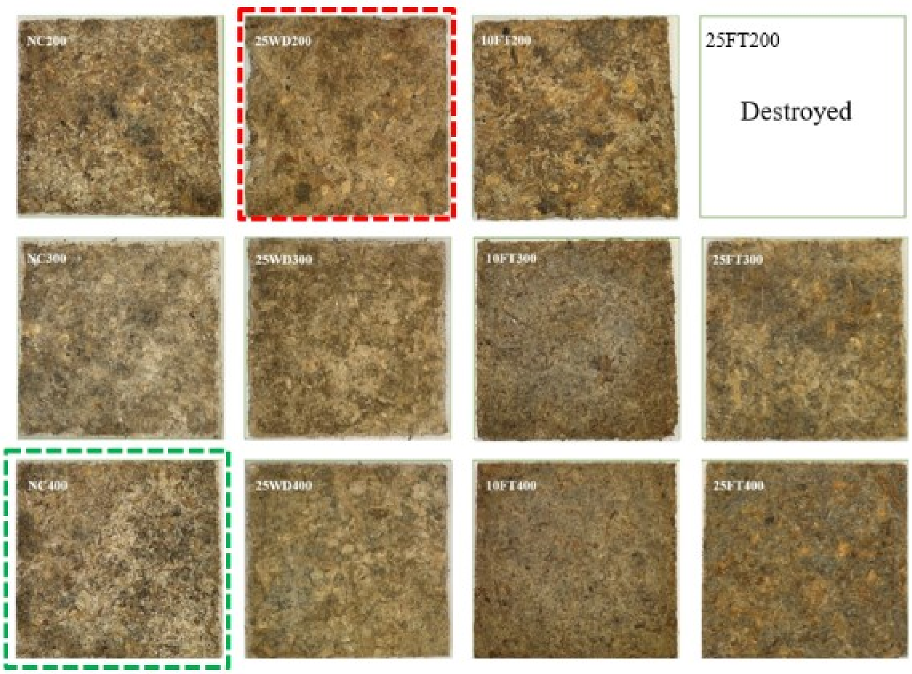


Figure 4.6: Failure Rate of alkali-activated particle board specimens.

Figure *4.6* illustrates the failure modes of particle boards made from alkali-activated concrete with varying degrees of damage. It is obvious that the surfaces of all specimens exhibited rough textures, and there was an increase in the extent of corner loss in specimens subjected to freezing-thawing cycles. For instance, considering the 10FT300 specimen as a representative, its surface underwent minimal alteration when compared to the NC300 specimen, which underwent 10 cycles of freezing and thawing curing. However, after 25 freezing-thawing cycles, the specimen's surface became notably rougher. This was accompanied by the detachment of small mortars that fell off from corners and the emergence of micro-cracks on the surface. Additionally, noticeable swelling was observed on the specimens' surfaces due to the presence of agro-waste in the material composition. This swelling became more pronounced after 25 cycles of freezing and thawing conditions.

Furthermore, the quantity of alkali-activated paste exerts a notable influence on the deterioration process of the specimens. At the same freezing-thawing cycles, it is obvious that lower amounts of alkali-activated paste within the particle board specimens lead to more pronounced degradation. This trend is illustrated in Figure **Figure *4.6***, where the NC400 specimen displayed negligible changes after undergoing 10 and 25 freezing-thawing cycles. The specimen exhibited only slight swelling, with no conspicuous alterations. In contrast, the 25FT200 specimen experienced significant deterioration, while the 25FT300 and 25FT400 specimens demonstrated even more pronounced degradation when compared to specimens subjected to standard curing conditions.
Upon completion of 25 freezing-thawing cycles, discernible damage became apparent on the edges of the 25FT300 prismatic specimens. Furthermore, the edges of the 10FT300 specimens began to peel off following 10 freezing-thawing cycles. Remarkably severe surface damage was observed in the case of the 25FT300 and 10FT200 specimens after 25 freezing-thawing cycles. Notably, the mortar layer on the surface of the 25FT300 specimens had entirely dislodged, leaving the agro-waste aggregate exposed. The degradation of the 10FT200 specimen was even more pronounced, with substantial peeling of the concrete edges and the presence of wider cracks on the surface.
Also, in the curing of wetting and drying cycles, a higher content of alkali-activated paste has been found to contribute to a reduced level of degradation in particle board specimens, and it is similar to the trend observed during freezing and thawing cycles. As illustrated in **Figure *4.6***, a discernible contrast in degradation severity is evident between the 25WD200 and 25WD400 specimens. Notably, it is important to highlight that the extent of degradation observed during wetting and drying cycles was much more than that observed during freezing and thawing cycles.
For instance, a notable comparison can be drawn between the degradation levels of the 25WD300 and 25FT300 specimens. Impressively, the 25WD300 specimen highlighted more pronounced degradation than its freezing and thawing cycle counterpart, 25FT300. On closer examination, it becomes evident that after undergoing 25 cycles of wetting and drying curing conditions, the surface of the specimens exhibited significant changes. The mortar layer had undergone complete detachment, leading to the formation of small pits, thereby exposing the coarse aggregate on the surface. Furthermore, at the edges of the specimens, severe peeling of the alkali-activated material had occurred, resulting in the appearance of wider cracks on the surface.

4.3.5 Mass Loss

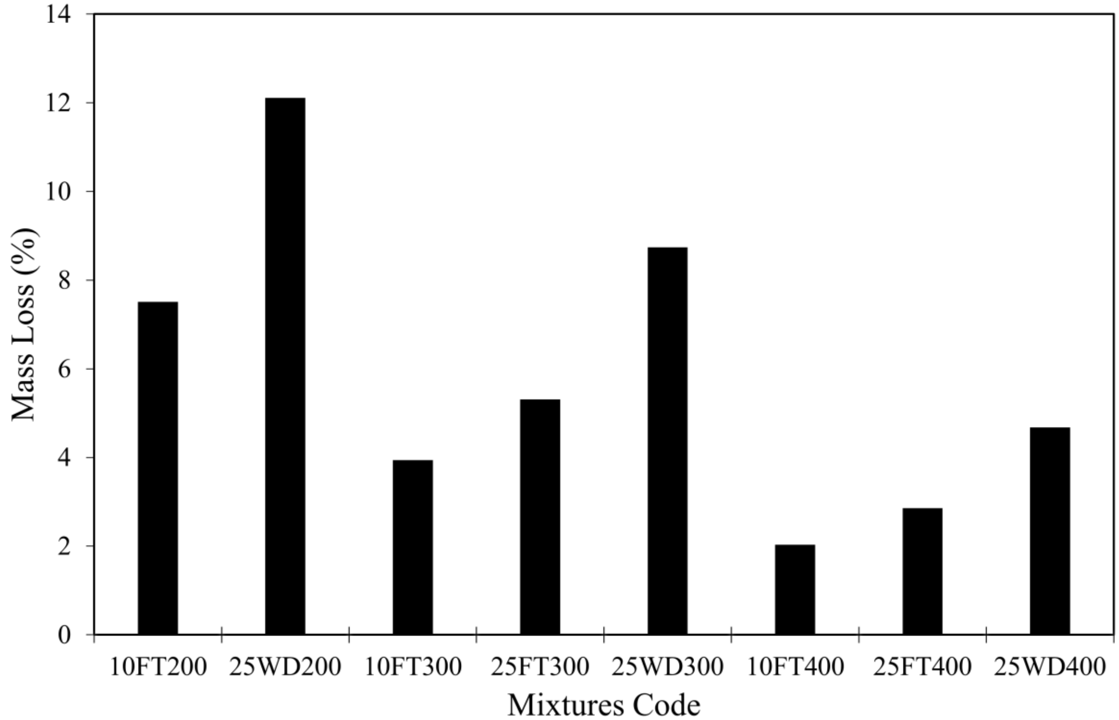


Figure 4.7: Effect of freezing-thawing and wetting-drying cycle on the mass loss of agro-waste alkali-activated particle board.

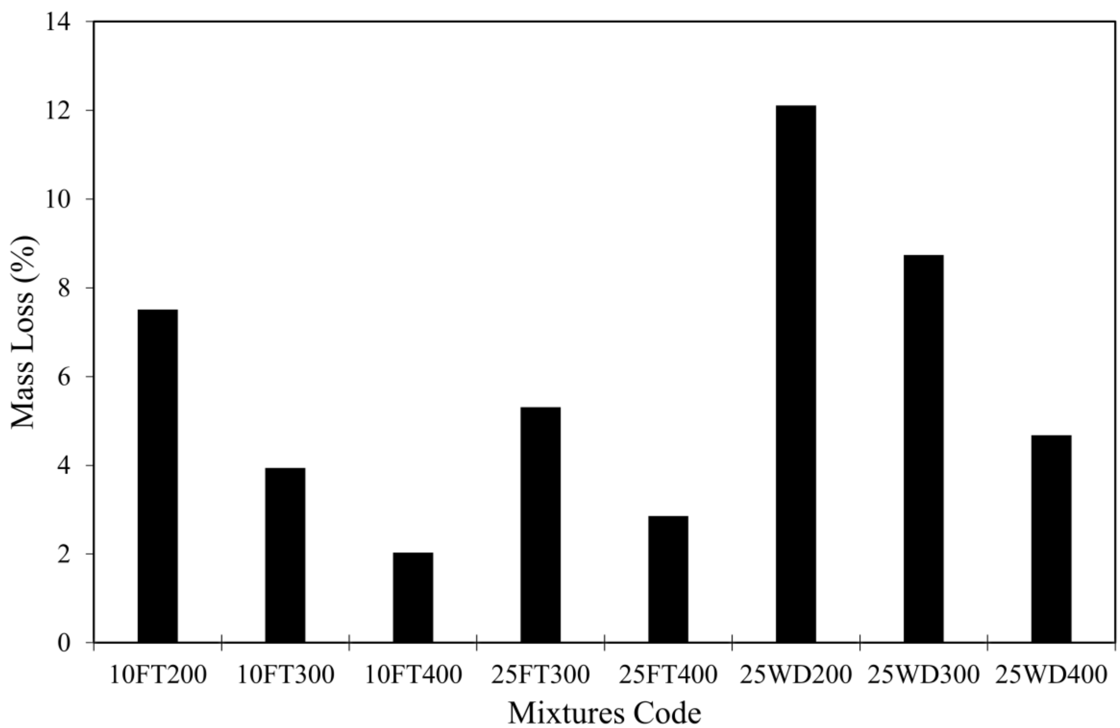


Figure 4.8: Effect of freezing-thawing and wetting-drying cycle on the mass loss of agro-waste alkali-activated particle board.

Figure ***4.7*** and **Figure** ***4.8*** illustrate the correlation between mass loss and the accumulation of freezing-thawing and wetting-drying cycles.

Generally, curing of particle board specimens under freezing-thawing or wetting-drying conditions leads to the loss of mass. A consistent elevation in mass loss is observed as the number of freezing-thawing and wetting-drying cycles increases. For instance, the 25FT300 specimen exhibited a more substantial mass loss compared to the 10FT300 specimen, with respective values of 5.31% and 3.94% as shown in Fig ().

This observation can be attributed to the following rationales. The change in particle board specimen mass during freezing-thawing, wetting and drying degradation can be delineated into two distinct phases. In the initial phase, the expansion stress induced by freezing triggers specimen cracking. Consequently, a transfer of external water permeates internal voids and cracks, contributing to an augmented particle board specimen mass. However, as the freezing-thawing and wetting-drying cycles progress, escalating freeze-thawing or wetting-drying damage results in more degradation fragments from the specimen. This occurrence leads to a reduction in mass. Subsequently, when the mass loss attributed to spalling surpasses the mass gain stemming from absorbed water, an overall reduction in particle board specimen mass ensues, thereby accentuating the magnitude of mass loss.

In the specimen of 10FT400, subjecting the particle board specimen to 10 freezing thawing cycles was not enough to trigger peeling. However, the 25WD200 specimen displayed the highest change in mass variations, amounting to approximately 12.11%. Moreover, it is notable that wetting-drying cycles exhibit a greater degradation potential when compared to freezing-thawing curing conditions, even when considering an equivalent number of cycles. This contrast is evident when examining the 25WD400 and 25FT400 specimens. The former demonstrated a mass loss of 4.68%, whereas the latter experienced a loss of 2.86%, as shown in Figure (). Additionally, the higher amount of alkali-activated paste in the specimen leads to a lower percentage of mass loss. For example, the 25WD200 had more changes in mass compared to the 25WD300, and 25WD400 which had 12.11%, 8.74%, and 4.68%, respectively.

4.3.6 Flexural Strength

4.3.6.1 Flexural Strength in repeated wetting and drying cycle

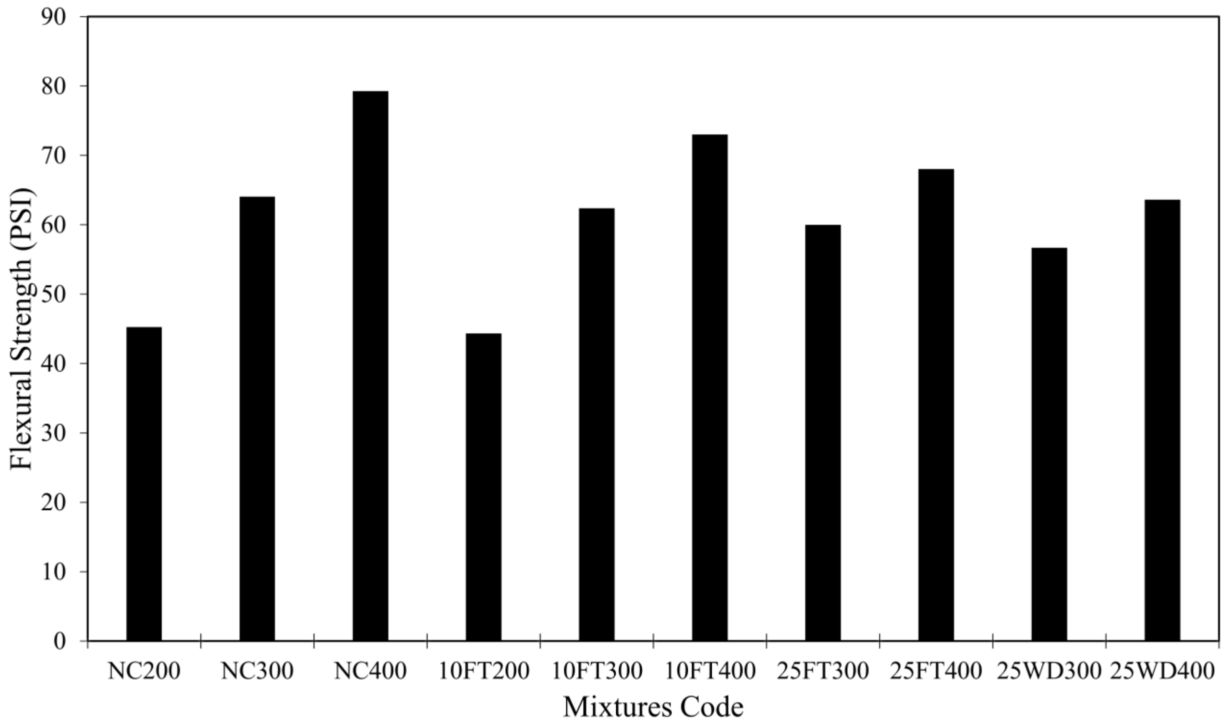


Figure 4.9: Effect of freezing-thawing and wetting-drying cycle on flexural strength of agro-waste alkali-activated particle board.

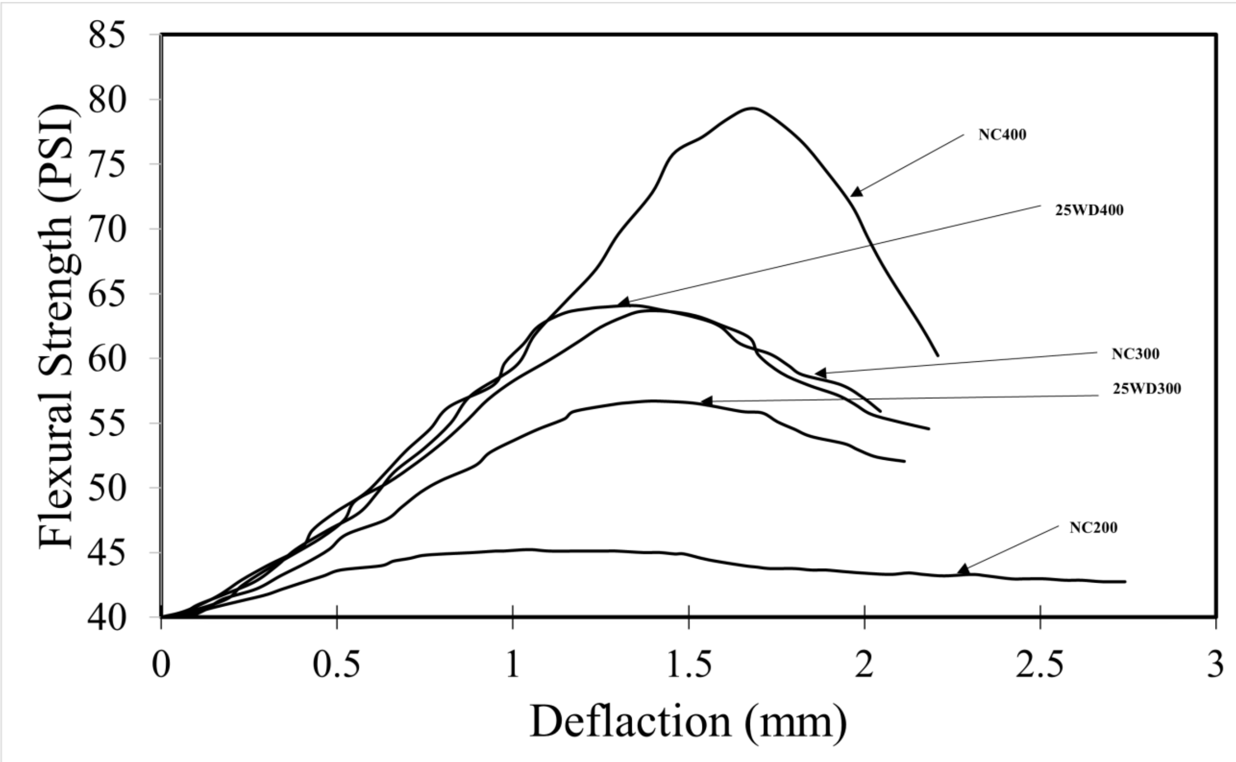


Figure 4.10: Effects of the wetting-drying cycle on the flexural curve characteristics of Alkali-activated particleboard.

Wetting-drying curing conditions were conducted to analyze the aging characteristics of alkali-activated particleboard. Flexural strength tests were carried out on an alkali-activated particle board under 25 cycles of repeated wetting-drying curing conditions. The impact of cyclic wetting-drying on the flexural behavior and results of the flexural tests, encompassing parameters such as strength and flexural load deflection is graphically shown in **Figure *4.9*** and **Figure *4.10*** , respectively.

Generally, the repeated wetting-drying cycles resulted in decreasing flexural strength. The flexural performance of alkali-activated particleboard in wetting-drying curing conditions versus normal curing condition specimens generally declined. For instance, the 25WD200 particle board specimen experienced more pronounced degradation, resulting in a complete loss of flexural strength. In contrast, the NC 200 variant exhibited a flexural strength of 42.24 PSI. The results were better with an agro-waste/ slag ratio of 0.25 when compared with 0.5. For instance, the flexural strength of 25WD300 and 25WD400 are about 56 PSI and 63 PSI, respectively.

4.3.6.2 Flexural Strength in freezing and thawing cycle

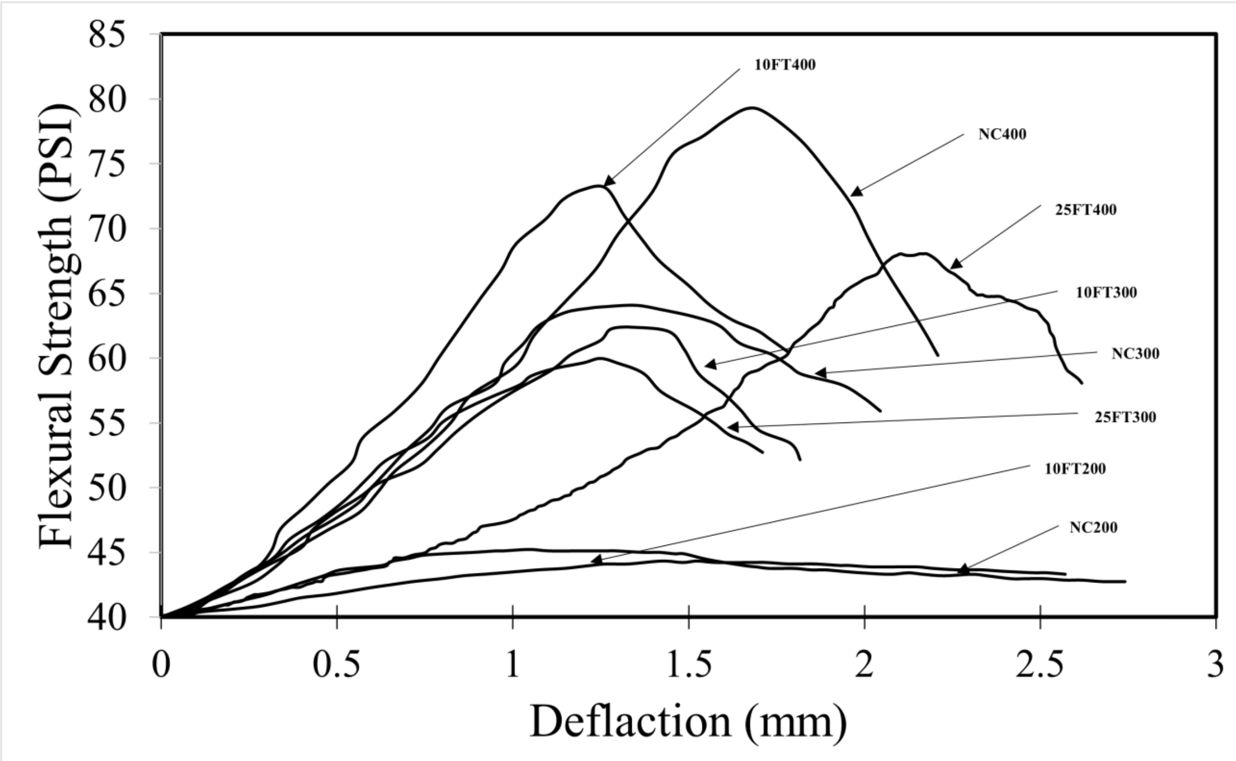


Figure 4.11: Effects of the freezing-thawing cycle on the flexural curve characteristics of Alkali-activated particleboard.

Freezing-thawing curing conditions were conducted to analyze the aging characteristics of alkali-activated particleboard. Flexural strength tests were carried out on an alkali-activated particle board under 10 and 25 cycles of freezing and thawing curing conditions. The impact of cyclic wetting-drying on the flexural behavior and results of the flexural tests, encompassing parameters such as strength, flexural load, and deflection is graphically shown in **Figure *4.9*** and **Figure *4.11*** , respectively.

Generally, the freezing and thawing curing conditions resulted in decreasing flexural strength. The flexural performance of alkali-activated particleboard in freezing-thawing curing conditions versus normal curing condition specimens generally declined. For instance, the 25FT200 particle board specimen experienced more pronounced degradation, resulting in a complete loss of flexural strength. In contrast, the NC 200 variant exhibited a flexural strength of 42.24 PSI. Moreover, the results showed that increasing the number of cycles from 10 to 25 cycles led to a decrease in flexural strength. For instance, the 10FT300 particle board specimen had 62.3 PSI but the 25FT300 had 59.9 PSI flexural strength. The results were better with an agro-waste/ slag ratio of 1:3 when compared with 1:4. For instance, the flexural strength of 10FT300 and 25FT400 is about 59.9 PSI and 68 PSI, respectively.

4.3.7 Thermal Performance

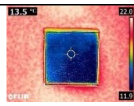
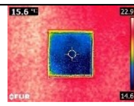
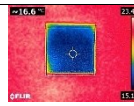
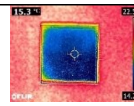
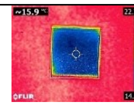
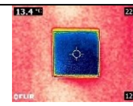
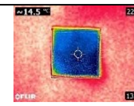
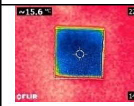
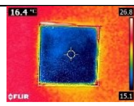
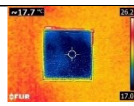
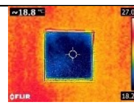
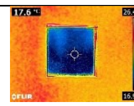
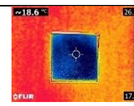
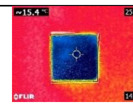
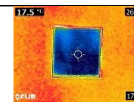
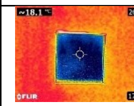
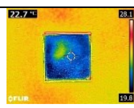
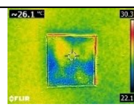
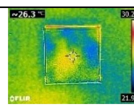
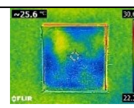
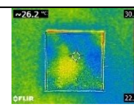
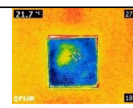
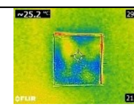
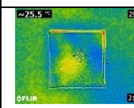
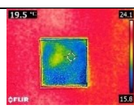
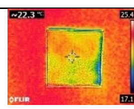
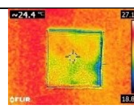
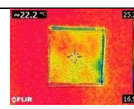
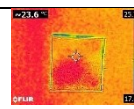
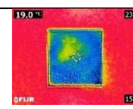
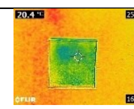
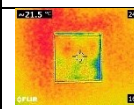
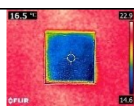
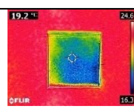
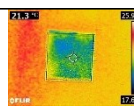
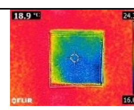
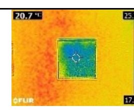
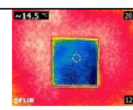
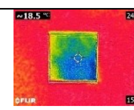
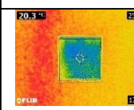
# point	NC200	NC300	NC400	25FT300	25FT400	25WD200	25WD300	25WD400
1								
2								
3								
4								
5								

Figure 4.12: Result of Thermal Performance of Alkali-activated agro-waste particle boards.

First, all particle board specimens were allowed to cool to 15 °C temperature for 25 min from ambient. Then the specimens were heated to 30 °C and kept for 30 min. then the temperature reached 15 °C in 10 min and kept it for 20 min. The result of the thermal performance of alkali-activated agro-waste concrete tile is shown in the **Figure *4.12***. It shows the temperature changes over time from the surface of samples containing agro-waste in an alkali-activated particle board. The results show that use of higher amounts of slag in the particle boards specimens lead to show higher temperature in the surface of specimens. For example, the temperature of surface of NC400 in all periods of monitoring is much more than of NC200. Also, wetting-drying and freezing-thawing curing condition followed the same trend as normal curing condition. On this way, with increasing the amount of slag content, the temperature of surface increased in all periods. However, as can be seen in **Figure *4.12***, the wetting-drying and freezing-thawing curing condition had negative effect on the thermal performance of alkali-activated agro-waste particle board. On this way, the thermal performance decreased when the specimens were cured under the wetting-drying or freezing and thawing curing condition. For instance, the 25FT300 and 25WD300 showed lower temperature in comparison with NC300. Also, wetting-drying curing condition had more negative effect in comparison with freezing and thawing curing condition. For instance, the surface temperature of 25WD400 in 3^{rd} period of monitoring showed 25.5 °C but the 25FT400 showed 26.6 °C which prove that wetting-drying cycle has more effect on the specimens.

4.4 Conclusion

This study demonstrates the negative effect of curing on the long-term structure and durability characteristics of alkali-activated agro-waste particleboard composite. Based on the findings and discussion presented, it can be firmly concluded that utilizing agricultural waste in the production of alkali-activated particleboard is a viable approach. The study also investigated the long-term durability properties of cement-bonded wood particleboards, specifically examining the impact of accelerated aging on the flexural performance of agricultural waste. Additionally, the influence of varying slag amounts was assessed, with the general trend showing that increasing slag content resulted in higher flexural strength. However, wetting-drying and freezing-thawing curing conditions were found to reduce flexural strength.

Key observations from the test results include:

- Repeated wetting-drying curing conditions and freezing-thawing cycles led to decreased flexural strength over time.
- Aging effects tended to increase the pore volume, particularly in the case of repeated wetting-drying cycles but had comparatively smaller effects in freezing-thawing cycles.
- From a practical perspective, the ratio of agricultural waste to slag, and aging on flexural strength were relatively big.
- Agricultural waste exhibited a lower specific gravity, resulting in a more porous structure and lower product density during curing.
- The increased porosity of agricultural waste led to less noticeable petrifaction (hardening) of agro-waste aggregate.

- Increasing the slag content in particle board specimens led to higher surface temperatures, but wetting-drying and freezing-thawing curing conditions had a negative impact on thermal performance, with wetting-drying having a more pronounced effect compared to freezing and thawing.

This study highlights the adverse impact of curing on the long-term structure and durability characteristics of alkali-activated particleboard composites made from agricultural waste.

CHAPTER 5: Conclusion and Future Work

Based on the conducted extensive experimental work the following can be concluded:

1. Usage of agro waste in the construction industry is an eco-friendly environmental solution that can be used in various industrial applications according to their physical and chemical properties.
2. The study confirms the potential to produce cement-based concrete tiles and alkali-activated particle boards with optimization of agro-waste content.
3. The low strength of cement-based concrete tile can be used for non-structural applications.
4. The use of a high amount of agro-waste in concrete tile and particle board leads to lower strength in mechanical properties.
5. Use of agro-waste leads to a reduction in workability due to the porous microstructure of agro-waste.
6. Adding agro-waste in concrete leads to higher water absorption and lower density.
7. For future studies in the concrete tile chapter, the research can continue in the alkali-activated part and a variety of agro-waste and different types of agro-waste that are applicable in this field.
8. For future studies in the alkali-activated particle board chapter, the research can continue in the two-part alkali-activated and with different types of solutions. Also, the variety of agro-waste based on their characteristics can be used in this fie

REFERENCES

[1] J. A. Foley *et al.*, "Global consequences of land use," *science,* vol. 309, no. 5734, pp. 570-574, 2005.

[2] P. M. Vitousek, H. A. Mooney, J. Lubchenco, and J. M. Melillo, "Human domination of Earth's ecosystems," *Science,* vol. 277, no. 5325, pp. 494-499, 1997.

[3] S. J. Cooke *et al.*, "Overcoming the concrete conquest of aquatic ecosystems," *Biological conservation,* vol. 247, p. 108589, 2020.

[4] W. B. Meyer and B. L. Turner, "Human population growth and global land-use/cover change," *Annual review of ecology and systematics,* vol. 23, no. 1, pp. 39-61, 1992.

[5] U. Berardi, "Sustainable construction: green building design and delivery," ed: Taylor & Francis, 2013.

[6] A. Horvath, "Construction materials and the environment," *Annu. Rev. Environ. Resour.,* vol. 29, pp. 181-204, 2004.

[7] N. B. Morse *et al.*, "Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications," *Ecology and Society,* vol. 19, no. 2, 2014.

[8] J. Watts, "Concrete: the most destructive material on Earth," *The Guardian,* vol. 25, pp. 1-9, 2019.

[9] C. N. Johnson *et al.*, "Biodiversity losses and conservation responses in the Anthropocene," *Science,* vol. 356, no. 6335, pp. 270-275, 2017.

[10] C. R. Gagg, "Cement and concrete as an engineering material: An historic appraisal and case study analysis," *Engineering Failure Analysis,* vol. 40, pp. 114-140, 2014.

[11] R. Geyer, J. R. Jambeck, and K. L. Law, "Production, use, and fate of all plastics ever made," *Science advances,* vol. 3, no. 7, p. e1700782, 2017.

[12] M. Shetty, "Concrete Technology Theory & Practice, Published by S," *CHAND & Company, Ram Nagar, New Delhi,* 2005.

[13] I. Baker, *Fifty materials that make the world*. Springer, 2018.

[14] T. Wangler *et al.*, "Digital concrete: opportunities and challenges," *RILEM Technical Letters,* vol. 1, pp. 67-75, 2016.

[15] P.-C. Aïtcin, "Cements of yesterday and today: concrete of tomorrow," *Cement and Concrete research,* vol. 30, no. 9, pp. 1349-1359, 2000.

[16] J. Zalasiewicz, C. Waters, and M. Williams, "The anthropocene," in *Geologic time scale 2020*: Elsevier, 2020, pp. 1257-1280.

[17] D. Ahadzadeh Ghanad, "Implementation of Agriculture Wastes in Different Construction Applications," Concordia University, 2020.

[18] R. Rosković and D. Bjegović, "Role of mineral additions in reducing CO2 emission," *Cement and Concrete Research,* vol. 35, no. 5, pp. 974-978, 2005.

[19] P. Shafigh, H. B. Mahmud, M. Z. Jumaat, and M. Zargar, "Agricultural wastes as aggregate in concrete mixtures–A review," *Construction and Building Materials,* vol. 53, pp. 110-117, 2014.

[20] B. Suhendro, "Toward green concrete for better sustainable environment," *Procedia Engineering,* vol. 95, pp. 305-320, 2014.

[21] S. Liu *et al.*, "Sustainable Use of Waste Oyster Shell Powders in a Ternary Supplementary Cementitious Material System for Green Concrete," *Materials,* vol. 15, no. 14, p. 4886, 2022.

[22] İ. Şanal, "Significance of concrete production in terms of carbondioxide emissions: Social and environmental impacts," *Politeknik Dergisi,* vol. 21, no. 2, pp. 369-378, 2018.

[23] M. S. Imbabi, C. Carrigan, and S. McKenna, "Trends and developments in green cement and concrete technology," *International Journal of Sustainable Built Environment,* vol. 1, no. 2, pp. 194-216, 2012.

[24] C. Garg and A. Jain, "Green concrete: Efficient & eco-friendly construction materials," *Int. J. Res. Eng. Technol,* vol. 2, no. 2, pp. 259-264, 2014.

[25] M. Holka, J. Kowalska, and M. Jakubowska, "Reducing Carbon Footprint of Agriculture—Can Organic Farming Help to Mitigate Climate Change?," *Agriculture,* vol. 12, no. 9, p. 1383, 2022.

[26] J. S. Damtoft, J. Lukasik, D. Herfort, D. Sorrentino, and E. M. Gartner, "Sustainable development and climate change initiatives," *Cement and concrete research,* vol. 38, no. 2, pp. 115-127, 2008.

[27] S. Ahmad, "Green human resource management: Policies and practices," *Cogent business & management,* vol. 2, no. 1, p. 1030817, 2015.

[28] P. Hazell and R. K. Pachauri, *Bioenergy and agriculture: promises and challenges*. IFPRI Washington, 2006.

[29] T. S. o. f. a. agriculture. "Choice Reviews Online. 46 (2009)." https://doi.org/10.5860/choice.46-5950 (accessed.

[30] U. Energy, "A Decision support tool for sustainable bioenergy," *Prepared by FAO and UNEP for UN Energy,* 2010.

[31] O.-F. A. Outlook, "OECD-FAO Agricultural Outlook 2017-2026," *Outlook,* vol. 2026, 2017.

[32] F. Gaspar, A. Bakatovich, N. Davydenko, and A. Joshi, "Building insulation materials based on agricultural wastes," in *Bio-based materials and biotechnologies for eco-efficient construction*: Elsevier, 2020, pp. 149-170.

[33] M. Adamson, A. Razmjoo, and A. Poursaee, "Durability of concrete incorporating crushed brick as coarse aggregate," *Construction and building materials,* vol. 94, pp. 426-432, 2015.

[34] E. Ganjian, G. Jalull, and H. Sadeghi-Pouya, "Using waste materials and by-products to produce concrete paving blocks," *Construction and Building Materials,* vol. 77, pp. 270-275, 2015.

[35] C. S. Poon and D. Chan, "Paving blocks made with recycled concrete aggregate and crushed clay brick," *Construction and building materials,* vol. 20, no. 8, pp. 569-577, 2006.

[36] S. Vanitha, V. Natarajan, and M. Praba, "Utilisation of waste plastics as a partial replacement of coarse aggregate in concrete blocks," *Indian journal of science and technology,* vol. 8, no. 12, p. 1, 2015.

[37] Z. Xiao, T.-C. Ling, S.-C. Kou, Q. Wang, and C.-S. Poon, "Use of wastes derived from earthquakes for the production of concrete masonry partition wall blocks," *Waste Management,* vol. 31, no. 8, pp. 1859-1866, 2011.

[38] Z. Xiao, T.-C. Ling, C.-S. Poon, S.-C. Kou, Q. Wang, and R. Huang, "Properties of partition wall blocks prepared with high percentages of recycled clay brick after exposure to elevated temperatures," *Construction and Building Materials,* vol. 49, pp. 56-61, 2013.

[39] L. Zhang, "Production of bricks from waste materials–A review," *Construction and building materials,* vol. 47, pp. 643-655, 2013.

[40] T.-C. Ling, "Prediction of density and compressive strength for rubberized concrete blocks," *Construction and Building Materials,* vol. 25, no. 11, pp. 4303-4306, 2011.

[41] T.-C. Ling, "Effects of compaction method and rubber content on the properties of concrete paving blocks," *Construction and Building Materials,* vol. 28, no. 1, pp. 164-175, 2012.

[42] T.-C. Ling, H. M. Nor, and M. R. Hainin, "Properties of crumb rubber concrete paving blocks with SBR latex," *Road Materials and Pavement Design,* vol. 10, no. 1, pp. 213-222, 2009.

[43] T.-C. Ling, H. M. Nor, and S.-K. Lim, "Using recycled waste tyres in concrete paving blocks," in *Proceedings of the Institution of Civil Engineers-Waste and Resource Management*, 2010, vol. 163, no. 1: Thomas Telford Ltd, pp. 37-45.

[44] B. S. Mohammed, K. M. A. Hossain, J. T. E. Swee, G. Wong, and M. Abdullahi, "Properties of crumb rubber hollow concrete block," *Journal of Cleaner Production,* vol. 23, no. 1, pp. 57-67, 2012.

[45] R. Siddique and T. R. Naik, "Properties of concrete containing scrap-tire rubber–an overview," *Waste management,* vol. 24, no. 6, pp. 563-569, 2004.

[46] E. Sodupe-Ortega, E. Fraile-Garcia, J. Ferreiro-Cabello, and A. Sanz-Garcia, "Evaluation of crumb rubber as aggregate for automated manufacturing of rubberized long hollow blocks and bricks," *Construction and Building materials,* vol. 106, pp. 305-316, 2016.

[47] P. Sukontasukkul and C. Chaikaew, "Properties of concrete pedestrian block mixed with crumb rubber," *Construction and Building Materials,* vol. 20, no. 7, pp. 450-457, 2006.

[48] I. Said, A. Missaoui, and Z. Lafhaj, "Reuse of Tunisian marine sediments in paving blocks: factory scale experiment," *Journal of Cleaner Production,* vol. 102, pp. 66-77, 2015.

[49] L. Wang, T. L. Yeung, A. Y. Lau, D. C. Tsang, and C.-S. Poon, "Recycling contaminated sediment into eco-friendly paving blocks by a combination of binary cement and carbon dioxide curing," *Journal of cleaner production,* vol. 164, pp. 1279-1288, 2017.

[50] J. Chen and C.-S. Poon, "Photocatalytic activity of titanium dioxide modified concrete materials–Influence of utilizing recycled glass cullets as aggregates," *Journal of Environmental Management,* vol. 90, no. 11, pp. 3436-3442, 2009.

[51] S.-H. Chen, C.-S. Chang, H.-Y. Wang, and W.-L. Huang, "Mixture design of high performance recycled liquid crystal glasses concrete (HPGC)," *Construction and Building Materials,* vol. 25, no. 10, pp. 3886-3892, 2011.

[52] Z. Chen, J. S. Li, and C. S. Poon, "Combined use of sewage sludge ash and recycled glass cullet for the production of concrete blocks," *Journal of Cleaner Production,* vol. 171, pp. 1447-1459, 2018.

[53] G. Lee, T.-C. Ling, Y.-L. Wong, and C.-S. Poon, "Effects of crushed glass cullet sizes, casting methods and pozzolanic materials on ASR of concrete blocks," *Construction and Building Materials,* vol. 25, no. 5, pp. 2611-2618, 2011.

[54] T.-C. Ling, C.-S. Poon, and H.-W. Wong, "Management and recycling of waste glass in concrete products: Current situations in Hong Kong," *Resources, Conservation and Recycling,* vol. 70, pp. 25-31, 2013.

[55] P. Turgut and E. Yahlizade, "Research into concrete blocks with waste glass," *International Journal of Civil and Environmental Engineering,* vol. 3, no. 3, pp. 186-192, 2009.

[56] T.-C. Ling and C.-S. Poon, "Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving blocks," *Journal of cleaner production,* vol. 68, pp. 209-215, 2014.

[57] T.-C. Ling and C.-S. Poon, "Use of CRT funnel glass in concrete blocks prepared with different aggregate-to-cement ratios," *Green Materials,* vol. 2, no. 1, pp. 43-51, 2014.

[58] T.-C. Ling, C.-S. Poon, W.-S. Lam, T.-P. Chan, and K. K.-L. Fung, "X-ray radiation shielding properties of cement mortars prepared with different types of aggregates," *Materials and structures,* vol. 46, pp. 1133-1141, 2013.

[59] O. Gencel, C. Ozel, F. Koksal, E. Erdogmus, G. Martínez-Barrera, and W. Brostow, "Properties of concrete paving blocks made with waste marble," *Journal of cleaner production,* vol. 21, no. 1, pp. 62-70, 2012.

[60] I. B. Topcu, T. Bilir, and T. Uygunoğlu, "Effect of waste marble dust content as filler on properties of self-compacting concrete," *Construction and building Materials,* vol. 23, no. 5, pp. 1947-1953, 2009.

[61] T. Uygunoğlu, I. B. Topcu, O. Gencel, and W. Brostow, "The effect of fly ash content and types of aggregates on the properties of pre-fabricated concrete interlocking blocks (PCIBs)," *Construction and Building Materials,* vol. 30, pp. 180-187, 2012.

[62] M. U. Hossain, D. Xuan, and C. S. Poon, "Sustainable management and utilisation of concrete slurry waste: A case study in Hong Kong," *Waste Management,* vol. 61, pp. 397-404, 2017.

[63] S.-C. Kou, B.-J. Zhan, and C.-S. Poon, "Properties of partition wall blocks prepared with fresh concrete wastes," *Construction and Building Materials,* vol. 36, pp. 566-571, 2012.

[64] M. Amin, I. Y. Hakeem, A. M. Zeyad, B. A. Tayeh, A. M. Maglad, and I. S. Agwa, "Influence of recycled aggregates and carbon nanofibres on properties of ultra-high-performance concrete under elevated temperatures," *Case Studies in Construction Materials,* vol. 16, p. e01063, 2022.

[65] E. Aprianti, P. Shafigh, S. Bahri, and J. N. Farahani, "Supplementary cementitious materials origin from agricultural wastes–A review," *Construction and Building Materials,* vol. 74, pp. 176-187, 2015.

[66] A. Rao, K. N. Jha, and S. Misra, "Use of aggregates from recycled construction and demolition waste in concrete," *Resources, conservation and Recycling,* vol. 50, no. 1, pp. 71-81, 2007.

[67] M. N. Soutsos, K. Tang, and S. G. Millard, "Concrete building blocks made with recycled demolition aggregate," *Construction and Building Materials,* vol. 25, no. 2, pp. 726-735, 2011.

[68] B. J. Zhan, D. X. Xuan, C. S. Poon, and C. J. Shi, "Effect of curing parameters on CO2 curing of concrete blocks containing recycled aggregates," *Cement and Concrete Composites,* vol. 71, pp. 122-130, 2016.

[69] C. Areeprasert *et al.*, "Municipal plastic waste composition study at transfer station of Bangkok and possibility of its energy recovery by pyrolysis," *Energy Procedia,* vol. 107, pp. 222-226, 2017.

[70] W. Raongjant, M. Jing, and P. Khamput, "Light weight Concrete Blocks by using Waste Plastic," *International Journal of Control Theory and Applications, ISSN,* pp. 0974-5572, 2016.

[71] P. Ricciardi, E. Belloni, F. Merli, and C. Buratti, "Sustainable panels made with industrial and agricultural waste: thermal and environmental critical analysis of the experimental results," *Applied Sciences,* vol. 11, no. 2, p. 494, 2021.

[72] N. A. Ramlee, J. Naveen, and M. Jawaid, "Potential of oil palm empty fruit bunch (OPEFB) and sugarcane bagasse fibers for thermal insulation application–A review," *Construction and Building Materials,* vol. 271, p. 121519, 2021.

[73] S. Mehrzad, E. Taban, P. Soltani, S. E. Samaei, and A. Khavanin, "Sugarcane bagasse waste fibers as novel thermal insulation and sound-absorbing materials for application in sustainable buildings," *Building and Environment,* vol. 211, p. 108753, 2022.

[74] R. Maderuelo-Sanz *et al.*, "Mechanical, thermal and acoustical evaluation of biocomposites made of agricultural waste for ceiling tiles," *Applied Acoustics,* vol. 191, p. 108689, 2022.

[75] M. Ali, A. Alabdulkarem, A. Nuhait, K. Al-Salem, G. Iannace, and R. Almuzaiqer, "Characteristics of agro waste fibers as new thermal insulation and sound absorbing materials: Hybrid of date palm tree leaves and wheat straw fibers," *Journal of Natural Fibers,* vol. 19, no. 13, pp. 6576-6594, 2022.

[76] F. Asdrubali, F. D'Alessandro, and S. Schiavoni, "A review of unconventional sustainable building insulation materials," *Sustainable Materials and Technologies,* vol. 4, pp. 1-17, 2015.

[77] A. Adazabra, G. Viruthagiri, and N. Shanmugam, "Infrared analysis of clay bricks incorporated with spent shea waste from the shea butter industry," *Journal of environmental management,* vol. 191, pp. 66-74, 2017.

[78] S. Singh *et al.*, "Performance behaviour of agro-waste based gypsum hollow blocks for partition walls," *Scientific Reports,* vol. 12, no. 1, p. 3204, 2022.

[79] L. V. Kumar and B. J. Vignesh, "Experimental Investigation on Replacement of Bagasse Ash in Bricks," *International Journal of Innovative Research in Science, Engineering and Technology,* vol. 6, no. 5, pp. 8302-8309, 2017.

[80] M. S. Arshad and P. Pawade, "Reuse of natural waste material for making light weight bricks," *International Journal of Scientific & Technology Research,* vol. 3, no. 6, pp. 49-53, 2014.

[81] M. S. Kazmi, M. J. Munir, S. Abbas, M. A. Saleem, A. Khitab, and M. Rizwan, "Development of lighter and eco-friendly burnt clay bricks incorporating sugarcane bagasse ash," *Pakistan Journal of Engineering and Applied Sciences,* 2017.

[82] A. Damanhuri, A. Lubis, A. Hariri, S. Herawan, M. Roslan, and M. Hussin, "Mechanical properties of Rice husk ash (RHA) brick as partial replacement of clay," in *Journal of Physics: Conference Series*, 2020, vol. 1529, no. 4: IOP Publishing, p. 042034.

[83] I. S. Agwa *et al.*, "A comprehensive review on the use of sugarcane bagasse ash as a supplementary cementitious material to produce eco-friendly concretes," *Materials Today: Proceedings,* vol. 65, pp. 688-696, 2022.

[84] N. Bheel, S. Khoso, M. H. Baloch, O. Benjeddou, and M. Alwetaishi, "Use of waste recycling coal bottom ash and sugarcane bagasse ash as cement and sand replacement material to produce sustainable concrete," *Environmental Science and Pollution Research,* vol. 29, no. 35, pp. 52399-52411, 2022.

[85] A. A. Jhatial, "Thermomechanical evaluation of sustainable foamed concrete incorporating palm oil fuel ash and eggshell powder," *Journal of Engineering Research,* vol. 9, no. 3A, 2021.

[86] W. E. Farrant, A. J. Babafemi, J. T. Kolawole, and B. Panda, "Influence of sugarcane bagasse ash and silica fume on the mechanical and durability properties of concrete," *Materials,* vol. 15, no. 9, p. 3018, 2022.

[87] S. H. Channa, S. A. Mangi, N. Bheel, F. A. Soomro, and S. H. Khahro, "Short-term analysis on the combined use of sugarcane bagasse ash and rice husk ash as supplementary cementitious material in concrete production," *Environmental Science and Pollution Research,* vol. 29, no. 3, pp. 3555-3564, 2022.

[88] N. K. Krishna, M. Prasanth, R. Gowtham, S. Karthic, and K. Mini, "Enhancement of properties of concrete using natural fibers," *Materials Today: Proceedings,* vol. 5, no. 11, pp. 23816-23823, 2018.

[89] W. Long and Y. Wang, "Effect of pine needle fibre reinforcement on the mechanical properties of concrete," *Construction and Building Materials,* vol. 278, p. 122333, 2021.

[90] B. C. Thomas and Y. S. Jose, "A study on characteristics of sisal fiber and its performance in fiber reinforced concrete," *Materials Today: Proceedings,* vol. 51, pp. 1238-1242, 2022.

[91] S. Pirmohammad and M. H. Mengharpey, "Influence of natural fibers on fracture strength of WMA (warm mix asphalt) concretes using a new fracture test specimen," *Construction and Building Materials,* vol. 251, p. 118927, 2020.

[92] C. Chen *et al.*, "Comparative analysis of natural fiber reinforced polymer and carbon fiber reinforced polymer in strengthening of reinforced concrete beams," *Journal of cleaner production,* vol. 263, p. 121572, 2020.

[93] M. Asim *et al.*, "Comparative experimental investigation of natural fibers reinforced light weight concrete as thermally efficient building materials," *Journal of Building Engineering,* vol. 31, p. 101411, 2020.

[94] J. F. Castillo-Lara *et al.*, "Mechanical properties of natural fiber reinforced foamed concrete," *Materials,* vol. 13, no. 14, p. 3060, 2020.

[95] K. Gunasekaran, R. Ramasubramani, R. Annadurai, and S. P. Chandar, "Study on reinforced lightweight coconut shell concrete beam behavior under torsion," *Materials & Design,* vol. 57, pp. 374-382, 2014.

[96] K. Gunasekaran, R. Annadurai, and P. Kumar, "Long term study on compressive and bond strength of coconut shell aggregate concrete," *Construction and building materials,* vol. 28, no. 1, pp. 208-215, 2012.

[97] F. Falade, "An investigation of periwinkle shells as coarse aggregate in concrete," *Building and Environment,* vol. 30, no. 4, pp. 573-577, 1995.

[98] F. Falade, E. Ikponmwosa, and N. Ojediran, "Behaviour Of Lightweight Concrete Containing Periwinkle Shells At Elevated Temperature," 2010.

[99] K. Muthusamy, N. Nordin, G. Vesuvapateran, M. Ali, H. Harun, and H. Ullap, "Research Article Exploratory Study of Rubber Seed Shell as Partial Coarse Aggregate Replacement in Concrete," *Research Journal of Applied Sciences, Engineering and Technology,* vol. 7, no. 6, pp. 1199-1202, 2014.

[100] A. Jayaprithika and S. Sekar, "Stress-strain characteristics and flexural behaviour of reinforced Eco-friendly coconut shell concrete," *Construction and Building Materials,* vol. 117, pp. 244-250, 2016.

[101] J. Pinto *et al.*, "Corn cob lightweight concrete for non-structural applications," *Construction and Building Materials,* vol. 34, pp. 346-351, 2012.

[102] M. Maghfouri, P. Shafigh, V. Alimohammadi, Y. Doroudi, and M. Aslam, "Appropriate drying shrinkage prediction models for lightweight concrete containing coarse agro-waste aggregate," *Journal of Building Engineering,* vol. 29, p. 101148, 2020.

[103] P. O. Modani and M. Vyawahare, "Utilization of bagasse ash as a partial replacement of fine aggregate in concrete," *Procedia Engineering,* vol. 51, pp. 25-29, 2013.

[104] A. Sales and S. A. Lima, "Use of Brazilian sugarcane bagasse ash in concrete as sand replacement," *Waste management,* vol. 30, no. 6, pp. 1114-1122, 2010.

[105] P. Nóvoa, M. Ribeiro, A. Ferreira, and A. Marques, "Mechanical characterization of lightweight polymer mortar modified with cork granulates," *Composites science and technology,* vol. 64, no. 13-14, pp. 2197-2205, 2004.

[106] D. Panesar and B. Shindman, "The mechanical, transport and thermal properties of mortar and concrete containing waste cork," *Cement and Concrete Composites,* vol. 34, no. 9, pp. 982-992, 2012.

[107] T. Ganiron, "Effect of sawdust as fine aggregate in concrete mixture for building construction," *International Journal of Advanced Science and Technology,* vol. 63, no. 1, pp. 73-82, 2014.

[108] A. Mneina, A. Soliman, A. Ahmed, and M. El Naggar, "Engineering properties of controlled low-strength materials containing treated oil sand waste," *Construction and Building Materials,* vol. 159, pp. 277-285, 2018.

[109] W.-T. Kuo, H.-Y. Wang, C.-Y. Shu, and D.-S. Su, "Engineering properties of controlled low-strength materials containing waste oyster shells," *Construction and Building Materials,* vol. 46, pp. 128-133, 2013.

[110] Z. Z. Ismail and A. J. Jaeel, "A novel use of undesirable wild giant reed biomass to replace aggregate in concrete," *Construction and Building Materials,* vol. 67, pp. 68-73, 2014.

[111] T. Öztürk and M. Bayrakl, "The possibilities of using tobacco wastes in producing lightweight concrete," *Agricultural Engineering International: CIGR Journal,* 2005.

[112] *BS 874-2.1 : Methods for determining thermal insulating properties*, BSI, 1986.

[113] *IS 456:2000: Plain and Reinforced Concrete - Code of Practice, Indian Standards*, B. o. I. S. (BIS), 2000.

[114] A. Sankar, S. V. Srinivasarao, S. Sivasankaran, A. F. K. Basha, and Z. Ismail, "Survey on applications of coconut timber, shell and coir in construction industry," in *AIP Conference Proceedings*, 2023, vol. 2643, no. 1: AIP Publishing LLC, p. 030031.

[115] A. Yadav, A. Chandra, and S. Singh, "Study on application of waste plastic in the construction industry," *Materials Today: Proceedings,* vol. 64, pp. 1455-1458, 2022.

[116] D. Agrawal *et al.*, "Experimental effect of pre-treatment of rubber fibers on mechanical properties of rubberized concrete," *Journal of Materials Research and Technology,* 2023.

[117] A. C. Ganesh *et al.*, "Effect of Flyash-Rice Husk Ash Blend in the Energy Efficient Geopolymer Tiles Using Industrial Wastes," in *Materials Science Forum*, 2022, vol. 1048: Trans Tech Publ, pp. 403-411.

[118] U. Karsten, R. Schumann, and A. Mostaert, "Aeroterrestrial algae growing on man-made surfaces: what are the secrets of their ecological success?," *Algae and cyanobacteria in extreme environments,* pp. 583-597, 2007.

[119] M. V. Madurwar, R. V. Ralegaonkar, and S. A. Mandavgane, "Application of agro-waste for sustainable construction materials: A review," *Construction and Building materials,* vol. 38, pp. 872-878, 2013.

[120] N. Sathiparan, A. Anburuvel, and V. V. Selvam, "Utilization of agro-waste groundnut shell and its derivatives in sustainable construction and building materials–A review," *Journal of Building Engineering,* p. 105866, 2023.

[121] V. C. Srivastava, I. D. Mall, and I. M. Mishra, "Characterization of mesoporous rice husk ash (RHA) and adsorption kinetics of metal ions from aqueous solution onto RHA," *Journal of hazardous materials,* vol. 134, no. 1-3, pp. 257-267, 2006.

[122] K. Ramakrishnan, V. Ganesh, G. Vignesh, M. Vignesh, V. Shriram, and R. Suryaprakash, "Mechanical and durability properties of concrete with partial replacement of fine aggregate by sugarcane bagasse ash (SCBA)," *Materials Today: Proceedings,* vol. 42, pp. 1070-1076, 2021.

[123] A. Kanojia and S. K. Jain, "Performance of coconut shell as coarse aggregate in concrete," *Construction and Building Materials,* vol. 140, pp. 150-156, 2017.

[124] I. S. Agwa, O. M. Omar, B. A. Tayeh, and B. A. Abdelsalam, "Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete," *Construction and Building Materials,* vol. 235, p. 117541, 2020.

[125] T. M. Pham, Y. Y. Lim, S. Pradhan, and J. Kumar, "Performance of rice husk Ash-Based sustainable geopolymer concrete with Ultra-Fine slag and Corn cob ash," *Construction and Building Materials,* vol. 279, p. 122526, 2021.

[126] D. O. Nduka, B. J. Olawuyi, A. M. Ajao, V. C. Okoye, and O. M. Okigbo, "Mechanical and durability property dimensions of sustainable bamboo leaf ash in high-performance concrete," *Cleaner Engineering and Technology,* vol. 11, p. 100583, 2022.

[127] K. Yaswanth, J. Revathy, and P. Gajalakshmi, "Strength, durability and micro-structural assessment of slag-agro blended based alkali activated engineered geopolymer composites," *Case Studies in Construction Materials,* vol. 16, p. e00920, 2022.

[128] B. Sangmesh *et al.*, "Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review," *Construction and Building Materials,* vol. 368, p. 130457, 2023.

[129] S. S. Banu, J. Karthikeyan, and P. Jayabalan, "Effect of agro-waste on strength and durability properties of concrete," *Construction and Building Materials,* vol. 258, p. 120322, 2020.

[130] C. Maraveas, "Production of sustainable construction materials using agro-wastes," *Materials,* vol. 13, no. 2, p. 262, 2020.

[131] R. Rithuparna, V. Jittin, and A. Bahurudeen, "Influence of different processing methods on the recycling potential of agro-waste ashes for sustainable cement production: A review," *Journal of Cleaner Production,* vol. 316, p. 128242, 2021.

[132] D. Hazarika, N. Gogoi, S. Jose, R. Das, and G. Basu, "Exploration of future prospects of Indian pineapple leaf, an agro waste for textile application," *Journal of Cleaner Production,* vol. 141, pp. 580-586, 2017.

[133] A. ASTM C33, "Standard specification for concrete aggregates," *American Society for Testing and Material,* pp. 1-11, 2018.

[134] A. C143, "Standard test method for slump of hydraulic-cement concrete," ed: ASTM International Conshohocken, PA, 2017.

[135] H. Zhang, *Building materials in civil engineering*. Elsevier, 2011.

[136] C. ASTM, "39/C 39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," *Annual book of ASTM standards,* vol. 4, 2021.

[137] A. C-496, "Standard Test Method for Splitting Tensile of Cylindrical Concrete Specimens," *Annual Book of ASTM Standards, American Society for Testing and Materials,* vol. 4, pp. 1-6, 2017.

[138] A. Standard, "C78-09 (2009) Standard test method for flexural strength of concrete (using simple beam with third-point loading)," *ASTM International*.

[139] A. C157, "Standard test method for length change of hardened hydraulic-cement mortar and concrete," ed: ASTM international West Conshohocken, PA, 2017.

[140] A. ASTM, "C1585-20 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes," *West Conshohocken, PA: ASTM International,* 2020.

[141] A. S. f. Testing and Materials, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete (ASTM C 138)," ed, 2017.

[142] C. Astm, "597, Standard test method for pulse velocity through concrete," *ASTM International, West Conshohocken, PA,* 2016.

[143] *AASHTO TP 95-11, Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration*, A. A. o. S. a. H. T. Officials, 2011.

[144] R. B. Tangadagi, M. Manjunatha, S. Preethi, A. Bharath, and T. Reshma, "Strength characteristics of concrete using coconut shell as a coarse aggregate–A sustainable approach," *Materials Today: Proceedings,* vol. 47, pp. 3845-3851, 2021.

[145] R. M. Bathke, "THE VIAB~ l! TY OF MANUAllY PRODUCING AND USING CONCRETE ROOF TilES FOR LOW COST HOUSING IN SOUTH AfRICA," University of the Witwatersrand, Johannesburg, 1998.

[146] M. Maghfouri, P. Shafigh, and M. Aslam, "Optimum oil palm shell content as coarse aggregate in concrete based on mechanical and durability properties," *Advances in Materials Science and Engineering,* vol. 2018, pp. 1-14, 2018.

[147] G. Deng, Y. Ding, and S. Ren, "The study on the air pollutants embodied in goods for consumption and trade in China–Accounting and structural decomposition analysis," *Journal of Cleaner Production,* vol. 135, pp. 332-341, 2016.

[148] L. Yusriah, S. Sapuan, E. S. Zainudin, and M. Mariatti, "Characterization of physical, mechanical, thermal and morphological properties of agro-waste betel nut (Areca catechu) husk fibre," *Journal of Cleaner Production,* vol. 72, pp. 174-180, 2014.

[149] J. K. Prusty and S. K. Patro, "Properties of fresh and hardened concrete using agro-waste as partial replacement of coarse aggregate–A review," *Construction and Building Materials,* vol. 82, pp. 101-113, 2015.

[150] D. M. Al Saffar, A. J. Al Saad, and B. A. Tayeh, "Effect of internal curing on behavior of high performance concrete: An overview," *Case Studies in Construction Materials,* vol. 10, p. e00229, 2019.

[151] K. Al Rim, A. Ledhem, O. Douzane, R. M. Dheilly, and M. Queneudec, "Influence of the proportion of wood on the thermal and mechanical performances of clay-cement-wood composites," *Cement and Concrete Composites,* vol. 21, no. 4, pp. 269-276, 1999/08/01/ 1999, doi: https://doi.org/10.1016/S0958-9465(99)00008-6.

[152] B. S. Mohammed, M. Abdullahi, and C. K. Hoong, "Statistical models for concrete containing wood chipping as partial replacement to fine aggregate," *Construction and Building Materials,* vol. 55, pp. 13-19, 2014/03/31/ 2014, doi: https://doi.org/10.1016/j.conbuildmat.2014.01.021.

[153] S. Popovics, *Strength and related properties of concrete: a quantitative approach*. John Wiley & Sons, 1998.

[154] J. K. Prusty, S. K. Patro, and S. Basarkar, "Concrete using agro-waste as fine aggregate for sustainable built environment–A review," *International Journal of Sustainable Built Environment,* vol. 5, no. 2, pp. 312-333, 2016.

[155] K. Nagarajan, A. Balaji, K. S. Basha, N. Ramanujam, and R. A. Kumar, "Effect of agro waste α-cellulosic micro filler on mechanical and thermal behavior of epoxy composites," *International journal of biological macromolecules,* vol. 152, pp. 327-339, 2020.

[156] N. Tripathi, C. D. Hills, R. S. Singh, and J. S. Singh, "Offsetting anthropogenic carbon emissions from biomass waste and mineralised carbon dioxide," *Scientific reports,* vol. 10, no. 1, pp. 1-9, 2020.

[157] P. F. Busch and J. N. F. Holanda, "Potential use of coffee grounds waste to produce dense/porous bi-layered red floor tiles," *Open Ceramics,* vol. 9, p. 100204, 2022.

[158] K. Hornbostel, C. K. Larsen, and M. R. Geiker, "Relationship between concrete resistivity and corrosion rate–A literature review," *Cement and concrete composites,* vol. 39, pp. 60-72, 2013.

[159] T. M. C. Eugênio, J. F. Fagundes, Q. S. Viana, A. P. Vilela, and R. F. Mendes, "Study on the feasibility of using iron ore tailing (iot) on technological properties of concrete roof tiles," *Construction and Building Materials,* vol. 279, p. 122484, 2021.

[160] S. Luhar *et al.*, "Sustainable and renewable bio-based natural fibres and its application for 3D printed concrete: a review," *Sustainability,* vol. 12, no. 24, p. 10485, 2020.

[161] B. Tahmouresi, P. Nemati, M. A. Asadi, A. Saradar, and M. M. Moein, "Mechanical strength and microstructure of engineered cementitious composites: A new configuration for direct tensile strength, experimental and numerical analysis," *Construction and Building Materials,* vol. 269, p. 121361, 2021.

[162] J. M. Abed and B. A. Khaleel, "Effect of wood waste as a partial replacement of cement, fine and coarse aggregate on physical and mechanical properties of concrete blocks units," *International Journal of Integrated Engineering,* vol. 11, no. 8, pp. 229-239, 2019.

[163] B. S. Al Numan and J. K. Ahmed, "Effect of wood-particles aggregate percentage on some physical properties of concrete," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 574, no. 1: IOP Publishing, p. 012012.

[164] M. Valente, M. Sambucci, M. Chougan, and S. H. Ghaffar, "Reducing the emission of climate-altering substances in cementitious materials: A comparison between alkali-activated materials and Portland cement-based composites incorporating recycled tire rubber," *Journal of Cleaner Production,* vol. 333, p. 130013, 2022.

[165] G. F. Huseien *et al.*, "Alkali-activated mortars blended with glass bottle waste nano powder: Environmental benefit and sustainability," *Journal of cleaner production,* vol. 243, p. 118636, 2020.

[166] O. A. Mohamed, "A review of durability and strength characteristics of alkali-activated slag concrete," *Materials,* vol. 12, no. 8, p. 1198, 2019.

[167] J. L. Provis, "Alkali-activated materials," *Cement and concrete research,* vol. 114, pp. 40-48, 2018.

[168] A. Kuqo, A. K. Mayer, S. O. Amiandamhen, S. Adamopoulos, and C. Mai, "Enhancement of physico-mechanical properties of geopolymer particleboards through the use of seagrass fibers," *Construction and Building Materials,* vol. 374, p. 130889, 2023.

[169] K.-D. T. Thi, M.-C. Liao, and D.-H. Vo, "The characteristics of alkali-activated slag-fly ash incorporating the high volume wood bottom ash: Mechanical properties and microstructures," *Construction and Building Materials,* vol. 394, p. 132240, 2023.

[170] V. Athira, V. Charitha, G. Athira, and A. Bahurudeen, "Agro-waste ash based alkali-activated binder: Cleaner production of zero cement concrete for construction," *Journal of Cleaner Production,* vol. 286, p. 125429, 2021.

[171] D. A. Ghanad and A. Soliman, "Bio-based alkali-activated controlled low strength material: Engineering properties," *Construction and Building Materials,* vol. 279, p. 122445, 2021.

[172] U. Aras, H. Kalaycıoğlu, H. Yel, and S. Kuştaş, "Utilization of olive mill solid waste in the manufacturing of cement-bonded particleboard," *Journal of Building Engineering,* vol. 49, p. 104055, 2022/05/15/ 2022, doi: https://doi.org/10.1016/j.jobe.2022.104055.

[173] J. Hou, Y. Jin, W. Che, and Y. Yu, "Value-added utilization of wood processing residues into cement-bonded particleboards with admirable integrated performance," *Construction and Building Materials,* vol. 344, p. 128144, 2022/08/15/ 2022, doi: https://doi.org/10.1016/j.conbuildmat.2022.128144.

[174] S. O. Odeyemi, R. Abdulwahab, A. G. Adeniyi, and O. D. Atoyebi, "Physical and mechanical properties of cement-bonded particle board produced from African balsam tree (Populous Balsamifera) and periwinkle shell residues," *Results in Engineering,* vol. 6, p. 100126, 2020/06/01/ 2020, doi: https://doi.org/10.1016/j.rineng.2020.100126.

[175] I. O. Ohijeagbon *et al.*, "Physico-mechanical properties of cement bonded ceiling board developed from teak and African locust bean tree wood residue," *Materials Today: Proceedings,* vol. 44, pp. 2865-2873, 2021/01/01/ 2021, doi: https://doi.org/10.1016/j.matpr.2020.12.1170.

[176] L. Bufalino *et al.*, "Contrasting the major characteristics of pinewood and Amazon hardwoods to provide high-quality cement-bonded particleboards," *Construction and Building Materials,* vol. 394, p. 132219, 2023/08/29/ 2023, doi: https://doi.org/10.1016/j.conbuildmat.2023.132219.

[177] G. Faria, C. Chastre, V. Lúcio, and Â. Nunes, "Compression behaviour of short columns made from cement-bonded particle board," *Construction and Building Materials,* vol. 40, pp. 60-69, 2013/03/01/ 2013, doi: https://doi.org/10.1016/j.conbuildmat.2012.09.074.

[178] H. O. Olayiwola, "Development of geopolymer bonded wood composites," Stellenbosch: Stellenbosch University, 2021.

[179] P. Soroushian, J.-P. Won, and M. Hassan, "Durability and microstructure analysis of CO2-cured cement-bonded wood particleboard," *Cement and Concrete Composites,* vol. 41, pp. 34-44, 2013/08/01/ 2013, doi: https://doi.org/10.1016/j.cemconcomp.2013.04.014.

[180] G. El-Sayed, M. M. Atallah, and M. Ahmad, "Production of Fire-Resistant Particle Boards from some Agricultural Residues," *Journal of Soil Sciences and Agricultural Engineering,* vol. 12, no. 3, pp. 145-151, 2021.

[181] C. C. Ferrandez-Garcia, T. Garcia-Ortuño, M. T. Ferrandez-Garcia, M. Ferrandez-Villena, and C. E. F. García, "Fire-resistance, physical, and mechanical characterization of binderless rice straw particleboards," *BioResources,* vol. 12, no. 4, pp. 8539-8549, 2017.

[182] O. U. Emmanuel, A. Kuqo, and C. Mai, "Non-conventional mineral binder-bonded lignocellulosic composite materials: A review," *BioResources,* vol. 16, no. 2, p. 4606, 2021.

[183] *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*, A. C666, 1997.

[184] *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units*, A. C140/C140M-22a.

REFERENCES