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Enhancing the Properties of Concrete Mixture for Construction by Partially Replacing Mangrove Charcoal in Cement and Including Sawdust as an Additive with Sand

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Abstract

This study explores the use of mangrove charcoal and sawdust in concrete making to improve sustainability and reduce environmental impact such as release of carbon emission due to cement manufacturing and health problem and air pollution that caused from poor waste management of sawdust. This lightweight concrete's mechanical qualities are compared to conventional concrete using slump, water absorption, concrete density, and compressive strength tests. The results from all the test showed, when the percentage of mangrove charcoal and sawdust increased, the value of compressive strength, workability, water absorption and density of the concrete, decreased perpendicularly after both 7 and 28 days of curing. The mixtures with a higher percentage of replacement and additional materials became poor in mechanical behavior, including workability, water absorption, and durability. But the appropriate usage of these materials in concrete mixture, contributes in producing high quality concrete and reduces the demand of natural resources in the construction sector while promoting the utilization of waste.

1. Introduction

Construction companies choose concrete for both residential and commercial buildings because of its strength, durability, and versatility. Cement, crushed stones, fine aggregate, and water are just a few of the many ingredients that make it impossible to utilize as a stand-alone building material. However, overusing virgin building materials depletes natural resources and stresses the ecosystem [1]. This study seeks to determine if mangrove charcoal partially replaced cement and sawdust as additives to concrete sand.

The primary component of concrete, one of the most widely used building materials worldwide, is cement, which collectively contributes between 5% and 7% of global CO2 emissions. One of the biggest consumers of natural resources is the cement industry, which uses materials like gypsum, clay, and limestone that have been heated to about 1500 degrees Celsius [2]. So, the building industry is accountable for 6% of global greenhouse gas emissions, carbon dioxide emissions from the atmosphere are the primary driver of global warming. Furthermore, the majority of the 3 million tones sawdust produced in the United States each year ends up in landfills and might be harmful to one's health to dispose of sawdust outside [3].

Consequently, using mangrove charcoal as a cementitious material to partially replace cement in concrete reduces the amount of cement needed, which in turn reduces carbon dioxide emissions. On the other hand, recycling sawdust, a typical byproduct of wood manufacturing, and using it as an additive material with sand helps minimize waste by keeping it out of landfills and encouraging sustainable waste management. To achieve this, 5–20% of concrete will comprise mangrove charcoal and sawdust. In the Concrete Technology Laboratory at Universiti Tun Hussein Onn Malaysia, Pagoh, 30 concrete cubes (100mm x 100mm x 100mm) were tested for compressive strength, density, and water absorption. Therefore, the goal of this study is to use cement that incorporates alternative materials to find the most dependable percentage for the ratio of regular concrete mixes with excessive workability.

1.1 Objective

The study's objectives are to assess the mechanical properties and durability of concrete mixtures with partially replaced cement with mangrove charcoal and sawdust added to sand and also to find the ideal percentage of substitution and additional material in the concrete mixture.

2. Literature Review

This literature review will summarize prior research on using recycled sawdust and mangrove charcoal in concrete mixtures, focusing on their outcomes on compressive strength, workability, durability, and environmental impact. This analysis examines experimental data and real studies to ascertain the suitable ratios for incorporating these components into concrete, along with potential downsides and areas requiring further exploration. This literature review focuses on two materials which are mangrove charcoal as a substitute for cement and recovered sawdust as an additive with sand. Similarly, these experiments will prove whether these alternative and additive materials can compete with ordinary concrete.

2.1 Mangrove Charcoal's Physical Behavior

Density

When mangrove charcoal is added to concrete, this density range could affect both its general density and structural integrity. Because of their enormous density, which increases their durability over other trees, mangrove trees are the main providers of charcoal [4].

2.2 Mangrove Charcoal's Chemical Properties

Ash Content

The ash content is the non-combustible remnant that remains after the combustion of carbon, oxygen, Sulphur, and water. A minimal ash quantity is present in 6.34% of mangrove charcoal, as indicated by a previous research study [5]. Consequently, it does not have an impact on the environment, as it does not contribute to emissions. Further, mangrove charcoal has been demonstrated to be the most effective partial cement substitute.

Moisture Content

The moisture content of mangrove wood charcoal has been reduced as a consequence of pyrolysis and drying, resulting in the lowest moisture content of 5.58% [5]. The calorific value increases in conjunction with a reduction in the default moisture content. The direct use of coal may pose a challenge due to its high moisture content. This is essential to ensure the purity of the charcoal and its potential for use in the production of concrete.

Carbon Content

Fixed carbon is the portion of coal residual that remains after volatile matter is removed and the total moisture and ash content of the coal are subtracted. Despite the presence of trace quantities of hydrogen, oxygen, nitrogen, and Sulphur that are not carried away by the gases, the principal component is carbon. According to a previous investigation, mangrove wood charcoal contains the maximum fixed carbon content (68.78%) [5]. The amount of fixed carbon content is influenced by the quantity of ash content. Specifically, the more ash content, the less carbon content is generated, and the reverse is also true. This can also affect the caloric value of mangrove wood charcoal.

Adsorption Efficiency

Mangrove wood-derived charcoal exhibits an outstanding adsorption capacity for iron in seawater, uniquely at 0.38 dp, a particle size [6]. Because of that, augmenting the charcoal's efficacy in eliminating contaminants from water, this property is important for water filtration as the microscopic particle size strengthen the available surface area for adsorption

Sulphur Content

The Sulphur content of mangrove charcoal is rather low, approximately 0.029% [7]. This can be utilized to reduce the Sulphur level of coal, an essential measure for enhancing the quality of fuels employed in combustion systems. Conversely, due to its lower Sulphur content, it poses no threat to the environment.

2.3 Sawdust's Physical Behavior

Specific Gravity

The moist sawdust of coniferous species that is used in sawdust concrete has a specific gravity that ranges from 17% to 37%, as indicated by research [8]. Moreover, hardwood contains specific gravity that values from 0.30 to 0.99 and it is contingent upon different causes, like the morphology of the fibers, quality of the pulp, and chemical content [9].

Porosity

In aggregate, the sawdust had an initial porosity of approximately 80% for each sample [10]. The porosity of pine was significantly reduced as a consequence of sawdust compaction that the pelletized samples exhibited a variation of 58.4%. The consistent reduction of exterior particle pores while pelletizing and the closure of internal sawdust particle pores during the final stages of compaction, may reduce the porosity of sawdust [10].

Moisture Content

Determining the moisture content is an essential component of the sawdust production procedure. Moisture levels, either too high or too low can affect the overall standard of sawdust. This can result in the operation being halted or in the production of substandard products and distribution. A study in 2021 has reported moisture content states of 53.49% for the winter and 50.23% for the summer, which illustrated the seasonal variation in sawdust moisture content [11].

2.4 Sawdust's Chemical Behavior

Lignin, hemicellulose, and cellulose are the primary chemical elements of sawdust, accounting for 15–30%, 20–35%, and 35–60% of the dried weight, separately. Sawdust essentially contained 46.32% of carbon (C), 42.57% of oxygen (O), 5.95% of hydrogen (H). and 0.26% of nitrogen (N) [12]. While the average heating value (HHV) of sawdust ranges from 18.30 to 21.90 MJ/kg. Because of its chemical behavior, raw sawdust can be a reasonable energy source, particularly when torrefied, as it decreases its moisture content and raises its thermal value.

3. Methodology

A research methodology delineates the methods and approaches employed to identify and analyze data pertinent to the subject of the study. The study technique includes a variety of tests, including the compressive strength test, water absorption test, slump test, and concrete density test, which assisted in developing well-informed judgements based on the feasibility and likely satisfaction of including mangrove charcoal and sawdust in concrete manufacturing.

3.1 Flowchart of Methodology

Methodological flowcharts are important as they come up with a reasonable method that keep focus on the job, increasing manageability and efficiency. Figure 1 highlights the relevant work plan for the whole proposed project.

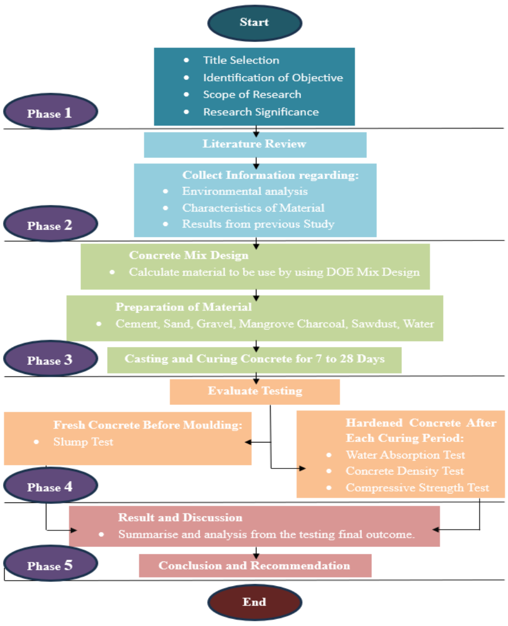

Fig. 1: Flowchart of Methodology

3.2 Selection of Material for Concrete

The basic materials utilized in this project include cement, fine aggregate, coarse aggregate, and water, while mangrove charcoal and recycled sawdust are utilized as partial replacement and additional material which is unusual than conventional concrete.

3.2.1 Sawdust

We are collaborating with Square Home Design Sdn. Bhd, a furniture manufacturing company, supplies sawdust for this research. We requested 3 kilograms of sawdust to use as additional material with sand, and with the help of the industry, I received more than 3 Kg, approximately 5 kg. The sawdust is gathered in a place during any furniture work being operated, including sawing, drilling, and grinding before disposal. Figure 1 show the sawdust taken from Square Home Design Sdn. Bhd.

Fig. 2: Sawdust

3.2.2 Mangrove Charcoal

Kuala Sepatang, the charcoal company located in Taiping, supplied us with mangrove charcoal. While we awaited the collection of mangrove charcoal, we reviewed the process of charcoal production, which encompassed the following steps of timber preparation, kiln loading, heating and pyrolysis, smoke monitoring, cooling, and ultimately, charcoal removal. Figure 2 shows the mangrove charcoal obtained from charcoal company at Kuala Sepatang, Taiping.

Fig. 3: Mangrove Charcoal

3.3 Preparation of Sample

3.3.1 Calculation for Concrete Cube Quantity

Sawdust was used as an additional substance in the calculated sand amount, while mangrove charcoal partially substituted cement in different percentages including 5%, 10%, 15%, and 20%. The cube test was conducted using a scale that measures 100mm × 100mm × 100mm. The trial mix utilized in this investigation was 0.0066 m^3, as indicated below.

Table 1: Calculation for Concrete Cube Quantity

Replacement and Additional Substance (%)	Amount of Concrete Cube 7 Day	28 Day
0	3	3
5	3	3
10	3	3
15	3	3
20	3	3
Total	**30**	

3.3.2 Concrete Mix Design

Picking up the appropriate ratios of water, admixtures, cementitious ingredients, and fine and coarse aggregate to produce concrete with the desired qualities and properties are the appropriate stages of designing concrete. [13]. The mix design's requirements are regularly picked depends on the concrete's structural element dimensions, essential physical behaviors, intended application, and exposure conditions. The quality of the concrete is significantly impacted by the type, behavior of the materials used, and quantity, as well as the placement, finishing, curing processes. The concrete admixture is mixed according the Department of Environment's (DOE) process. According to concrete standards, a compressive strength of 30 N/mm2 or above must be achieved in 28 days after curing as Grade 30 had been chosen for this project.

Table 2: Quantity of Material Used in Calculating the Design of a Concrete Mix (DOE)

Percentages (%)	Material Weight (KG) Cement	Mangrove Charcoal	Sand	Sawdust	Water	Coarse aggregate	Amount of Sample
0	2.34	0	4.104	0	1.26	6.696	6
5	2.223	0.117	4.104	0.205	1.26	6.696	6
10	2.106	0.234	4.104	0.410	1.26	6.696	6
15	1.989	0.351	4.104	0.616	1.26	6.696	6
20	1.872	0.468	4.104	0.821	1.26	6.696	6
Total	11.7		20.52	2.052	6.3	33.48	30

4. Result and Discussion

This section provides the outcome of experiments including the slump test, water absorption test, density test, and compressive strength test performed to assess the performance and characteristics of concrete mixtures made by the partial substitution of cement with mangrove charcoal and the incorporation of sawdust as an addition with sand. Any mismatch from predicted results is pointed out, and the possible source of these dissimilarities has been listed out with supporting evidence from experts or quote researchers. Furthermore, the results of the concrete testing will be proposed in the graphs, tables, and charts to advance the understanding and build up the explanation in more detail. This discussion of the result also provides a detailed knowledge of the innovative lightweight concrete's performance, while providing a valuable understanding of its standard and compliance to design specifications.

4.1 Workability of Concrete

A slump test is a procedure specified in BS EN 12350-2 to identify the uniformity of fresh concrete. The slump test is sensitive to swings or variations in the steadiness of concrete, which are representative of slumps ranging from 10 mm to 210 mm. Table 3 below illustrates, the value of slump obtained by conducting slump test on fresh concrete before moulding and all the value obtained were true slump. The goal of the concrete slump is to examine the workability of fresh concrete and, as a result, the ease with which it flows. While figure 3 displays the flow of slump value which is when the percentage of mangrove charcoal increased, the slump is decreased.

Table 3: Slump Test Result

Percentage of Replacement and Additive Material (%)	Slump Height (mm)	Type of Slump	Degree of Workability
0	33	True Slump	Low
5	30	True Slump	Low
10	22	True Slump	Low
15	13	True Slump	Very Low
20	13	True Slump	Very Low

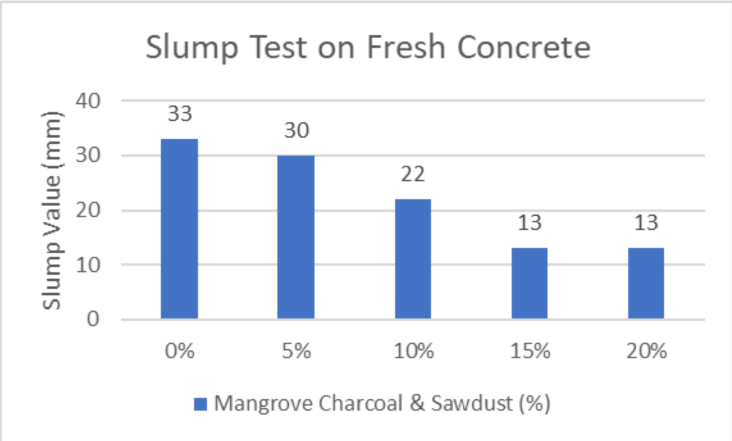

Fig. 3: Graph of Slump Test on Fresh Concrete Result for Different Percentage of Mangrove Charcoal and Sawdust

Figure 3 above illustrates the conventional concrete is the most workable mix without replacement and additives as it ranges from 30 to 60 mm. This shows the control concrete contained a sturdy concrete mix, typical of medium to low workability concrete slump levels. On the other hand, if the percentages of mangrove charcoal and sawdust are increased, the workability of the concrete mix is decreased. Because, the addition of these materials may increase the rate of water absorption as both of the materials are higher in porosity [14]. The increased ratio of mangrove charcoal and sawdust will facilitate the cement hydration however, it may affect the water-cement ratio, thereby reducing its workability, even not substantially [15].

4.2 Density

The density of concrete is identified by concrete density test using the formula of mass per unit volume. The average density of concrete cubes was identified by calculating every three cubes, each aged 7 and 28 days of curing.

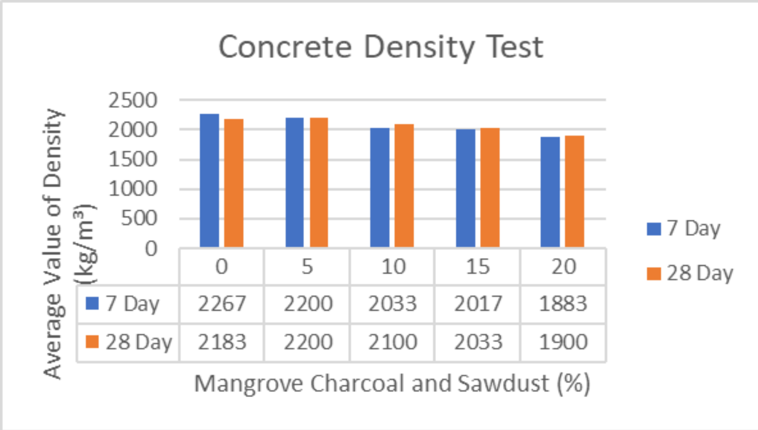

Fig. 4: Graph of Concrete Density Test at both 7 and 28 Day

Figure 4 above illustrates the average density value of concrete cube is decreased significantly following the percentages of mangrove charcoal and sawdust are increased. In following that, the weight of concrete in every mix differs as the concrete that contains more replacement material make the concrete structure lighter even sawdust is utilized as an additive material with the amount of sand. Furthermore, figure 4 also explains that the density of concrete at 28 days is increased from the density at 7 days according to the raise of percentage except the control mix and 5% as no or less presence of both initiative material which contains high level of porosity.

4.3 Water Absorption

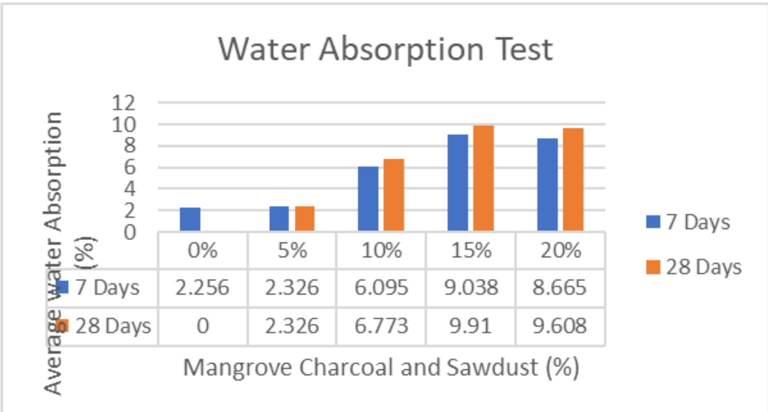

Fig. 5: Graph of Water Absorption Test at both 7 and 28 Day

According to this research findings on water absorption test, the presence of mangrove charcoal and sawdust caused the water absorption rate get higher compared with the conventional concrete which means if the percentage of material used is increased, the percentage of average water absorption value also increased significantly except 20%. For more detail, the lowest water absorption rate was stated by the conventional concrete, which was 2.256% after 7 days and 0% after 28 days. On the other hand, the water absorption rate of concrete that contained 15% mangrove and charcoal was 9.038% after 7 days and 9.91 after 28 days, which was the highest among others. Consequently, it is possible to determine that concrete that contains mangrove charcoal and sawdust in varying percentages does not perform well in the hydration process as it did not develop an opaque microstructure that keeps under control the free space available for water absorption [16].

4.4 Compressive Strength

The compressive strength is determined by utilizing the 3000 KN compression strength machine at Concrete Technology Laboratory, Universiti Tun Hussein Onn Malaysia, Pagoh, which comes with a monitor to generate the data automatically and give the average load failure value.

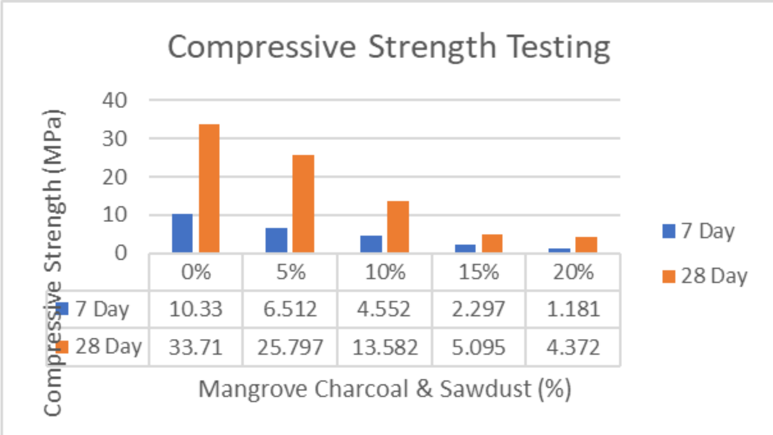

Fig. 6: Graph of Compressive Strength at both 7 and 28 Days

Figure 6 above illustrates a comparison graph that showing the direct down trendline among all the mixture. . In following that, if the percentages of mangrove charcoal and sawdust increased, while the compressive strength value was decreased approximately. For more detail, the highest compressive strength value, which was 10.33 MPa after 7 days, and 33.71 MPa after 28 days was reached by conventional concrete. While, 20% of mangrove charcoal and sawdust usage in concrete mixture showed the lowest compressive strength value with 1.181 MPa after 7 days while 4.372 after cured for 28 days. Furthermore, compressive strength of 5% was slightly stable or acceptable as it achieved 25.797 after 28 days which was got strong very fast compare with control as it was lower than control after 7 days of curing. Then, after 28 days of curing, the compressive strength of concrete cube samples with 10% and 15% of mangrove charcoal and sawdust were showed 13.582 MPa and 5.095 MPa.

To be summarized, the combination of mangrove charcoal as a substitute for cement in concrete frequently leads to diminished compressive strength owing to various intrinsic properties of biochar. Although biochar can improve some properties of concrete, its distinct structure and composition may result in diminished binding capacity and mechanical performance at elevated concentrations [17]. The microporous structure of mangrove charcoal can create cavities in the concrete matrix, adversely affecting its density and strength [18]. Moreover, sawdust may interact with cement hydration products, perhaps creating crystalline structures that improve strength when utilised in appropriate quantities. Excessive sawdust, however, also might result in heightened porosity and diminished density, adversely impacting strength [19].

5. Conclusion

In summary, this investigation summarizes that the mechanical properties of concrete are greatly influenced by both the partial replacement of cement with mangrove charcoal and the addition of sawdust as an additive. The results suggest that the workability, density, and compressive strength of the material are reduced as the percentage of these materials increases while the water absorption is increased. The durability and compressive strength of concrete production by replacing and adding 5% of mangrove charcoal and sawdust were acceptable, rendering them suitable for lightweight construction. Despite that, the properties of concrete were slightly minimized at higher replacement percentages (10% and above), mainly during water absorption and compressive strength. In general, the integration of mangrove charcoal and sawdust provides a sustainable alternative for the production of lightweight concrete, provided that their utilization is optimized to meet acceptable mechanical and durability standards.

Based on the final outcome of the study, several recommendations were proposed to identify the suitable way to use both mangrove charcoal and sawdust as replacement and additive material in order to improve quality of concrete for further studies. Primarily, these porous materials require more water as the presence of sawdust and mangrove charcoal contain higher water absorption and porosity. Thus, using water-reducing compounds or maintaining suitable amount these materials or adding more water into proposed proportion is highly recommended. Furthermore, long-term endurance under freeze-thaw cycles needs further study. Moreover, the potential for non-load-bearing applications, such as partition walls, soundproof panels, or decorative elements, could be investigated by incorporating higher percentages of mangrove charcoal and sawdust mixtures.

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