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Investigation of Lightweight Concrete Filled Sawdust for Thermal Properties

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Abstract

This study investigates sawdust as a sustainable alternative to sand in lightweight concrete production. It evaluates the effects of sawdust as a fine aggregate on the compressive strength and thermal conductivity of lightweight concrete. The research used cube molds for physical testing and panels for thermal conductivity testing, utilizing the Thermal Conductivity of Building Material Apparatus. Sawdust was incorporated at varying proportions, and a dry mixing method was employed. Cement, sawdust, and pumice were used in different proportions to create the concrete samples. The compressive strength tests showed a consistent decrease in strength as the sawdust content increased, with the highest strength in the mix without sawdust and the lowest in the mix with the highest sawdust content. Thermal conductivity measurements varied, indicating a decrease in thermal conductivity with more sawdust. The study highlights the importance of sawdust and pumice ratios in affecting the physical and thermal properties of lightweight concrete. It contributes to sustainable construction practices by exploring sawdust as a viable alternative material, enhancing the durability and efficiency of concrete structures, and showcasing sawdust as an eco-friendly option in construction materials.

1. Introduction

In recent years, the use of lightweight concrete in construction has increased. Lightweight concrete, used since 3000 BC [1], is defined as having a density between 1200 kg/m^3 and 2000 kg/m^3, compared to conventional concrete's 2400 kg/m^3 [2]. This study examines the effectiveness of replacing sand with sawdust as fine aggregate, focusing on its impact on thermal conductivity, compressive strength, and density. Lightweight concrete (LWC) is popular in construction due to its low density, low thermal conductivity, low shrinkage, and high heat resistance. Advancements in materials and cementing processes have improved its strength. LWC is a composite of traditional concrete mixed with lightweight substances, often replacing coarse aggregate [3].

Using waste materials in construction, particularly concrete projects, is an effective way to dispose of industrial waste, conserve natural resources, and protect the environment [4]. Sawdust, a byproduct of timber manufacturing, is often disposed of by dumping or burning, which harms the environment [5]. Sawdust is highly flammable and poses risks in industrial settings, requiring careful handling. Researchers studied the thermal properties of sawdust-cement composites and found that adding sawdust to concrete reduced its thermal conductivity by 23.2% due to the low density and high porosity of the composite [6]. However, using more than 25% sawdust as a replacement for sand in concrete negatively impacted its mechanical strength and density [7].

This study focuses on testing the density, compressive strength, and thermal conductivity of concrete containing sawdust and pumice. Concrete samples with 25%, 50%, 75%, and 100% sawdust replacement for sand were tested after curing for 7 and 28 days. The concrete mix used was M30 grade with a ratio of cement 3:1:1 and a water-cement ratio of 0.7. A total of 30 concrete cubes (100mm x 100mm x 100mm) for compressive tests and 2 concrete panels (300mm x 300mm x 10mm) for thermal conductivity tests were used.

This study identifies alternatives for partially substituting sawdust for other construction materials. Using sawdust in lightweight concrete is eco-friendly, reduces concrete density, and offers better thermal insulation. This is beneficial for applications requiring lightweight materials, such as precast parts, tall structures, and energy-efficient buildings. Repurposing sawdust in concrete can also reduce the construction industry's carbon footprint by reusing waste materials. The objectives of this research are to identify the optimum proportion of lightweight concrete filled with sawdust and pumice and to analyze the physical and thermal properties of lightweight concrete.

2. Methodology

There are three main materials use in this study which are saw dust, pumice and cement.

2.1 Research Methodology

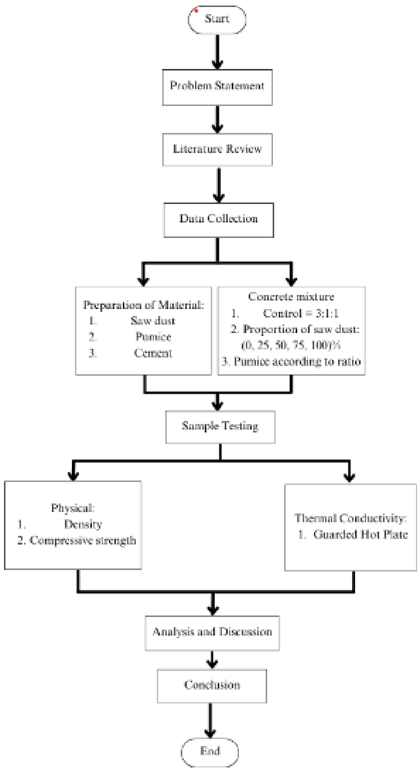

Fig. 1 *Methodology Flowchart*

2.2 Materials

Following the completion of the sieving process and the design of the concrete mix using the trial mix ratio , this study proceeded with the preparation of samples for laboratory testing.

2.2.1 Sawdust

In this study, sawdust will be used entirely as a substitute for sand. Sawdust was taken from Furniture Technology laboratory in UTHM Pagoh Campus. After the saw dust was taken, the sawdust was then sieved with 0 - 0.6mm sieve to imitate the actual size of sand without changing its properties. Figure 3.2 shows the raw saw dust taken from Furniture Technology laboratory.

Fig. 2 *Raw Sawdust*

2.2.2 Lightweight Aggregate (Pumice)

Pumice is often crushed and used as a lightweight aggregate in concrete and masonry products. It reduces the weight of concrete while maintaining its strength and insulation properties. Pumice concrete is commonly used in construction where reduced structural weight is essential, such as in building blocks, precast concrete products, and lightweight insulating concrete. The size of pumice used is 8-10mm and act as coarse aggregates.

Fig. 3 *Pumice*

2.2.3 Cement

In this study, the type cement will be used for concrete mixture is YTL Top Standard cement. Top Standard is a mainstay ECOCem product range. It is made with 30% to 40% lower CO_2 emissions and contains a minimum of 25% recycled material. Its ease of use and excellent workability make it one of the most widely- used multipurpose cements in the industry. It is suitable for the building of homes and commercial use.

Fig. 4 *Cement*

2.2.4 Water

The source of water that used is from tap water in UTHM Pagoh ConcreteTechnology Laboratory. Water is a critical ingredient in the concrete mix,playing a significant role in the hydration process of cement and helping to forma cohesive mixture that can be placed and shaped into the desired structure. For this study, water-cement ratio used is 0.70.

2.3 Methods for Laboratory Work

2.3.1 Proportion of Sawdust in Concrete

The proportion used for this study is locally sourced. Sawdust are obtained from online shop which MD Woodwork. Table presents the proportion of sawdust in concrete. The concrete mixtures have been test with the different percentage of proportion of sawdust fiber to determine the strength binder. Water and cement ratio of 0.7maintained for all mixes.

Table 1 *Trial Mix (Ratio 3:1:1)*

Mix No.	Cement	Sand	Sawdust (%)	Pumice	W/C
0SD	3	1	-	1	0.7
25SD	3	0.75	0.25	1	0.7
50SD	3	0.50	0.50	1	0.7
75SD	3	0.25	0.75	1	0.7
100SD	3	-	1.00	1	0.7

2.3.2 Concrete Mix Design

The concrete mix design added with sawdust fiber is 3:1:1. For concrete control, the ratio used is still the same but not combined with sawdust fiber. The sawdust fiber will be added according to the percentage that has been proposed. Table 2 shows the process of the concrete mixer by adding the sawdust fiber as the partial replacement of aggregates.

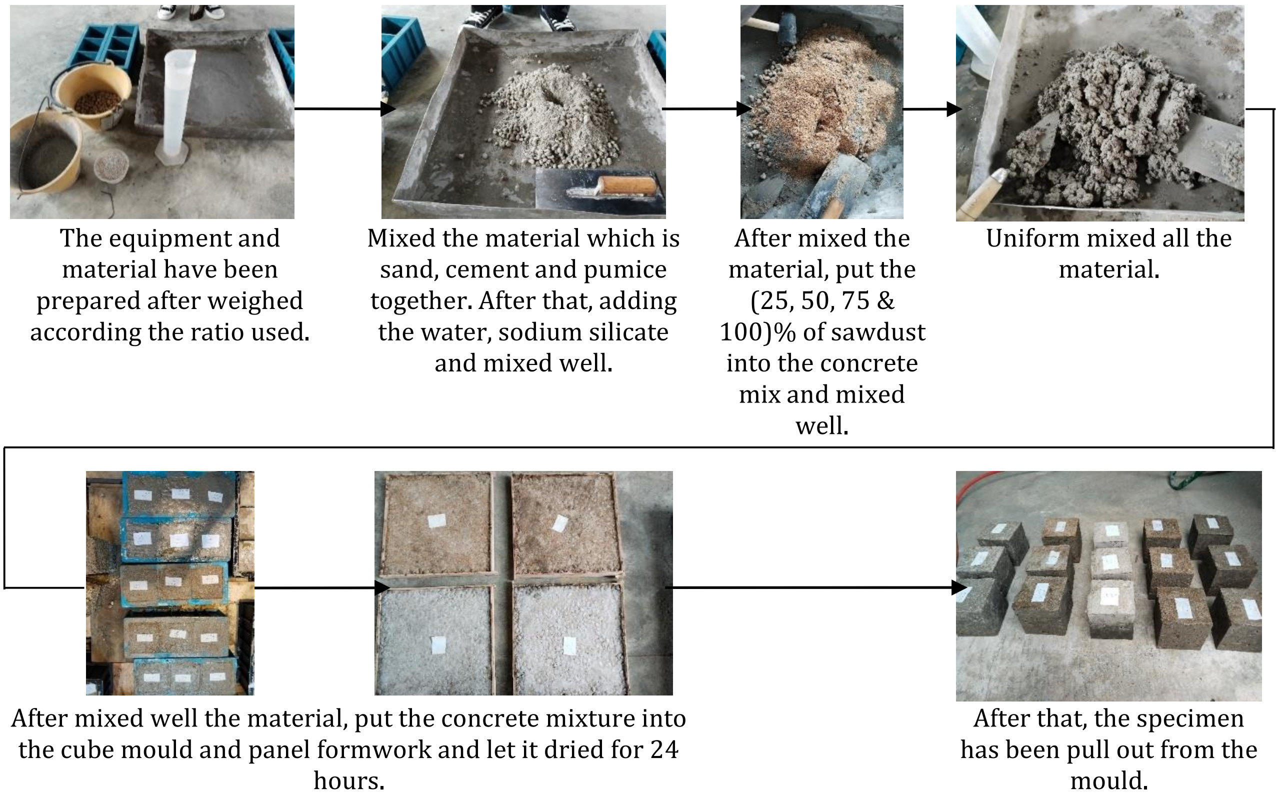

Fig 5. *Process of Concrete Mixer*

2.3.3 Compressive Strength

The compression test was conducted to determine the concrete's strength. The determination is made by utilising the compression test machine available in the Concrete Technology Laboratory of University Tun Hussein Onn Malaysia. Before conducting a compressive test, a cube mould of 100 mm x 100 mm x 100 mm is utilised to create the concrete samples. The concrete cube mould has been applied grease in the inside of the mould so that the hardened concrete cube will easy to remove when it is dry. The hardened concrete cube were removed from the

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mould after 24 hours in room temperature using an air compressor Curing is primarily designed to minimize moisture loss from the concrete throughout the process to achieve strength, therefore keeping the concrete soaked at room temperature (27°C). The curing process happened in the laboratory's by used dry curing for 7 and 28 days age of concrete.

2.3.4 Density

Density is the ratio of mass to volume. The consideration of concrete density percentage is crucial in the production of concrete. The concrete mass was determined by used dry curing method for 7 and 28 days. The volume of the concrete is 0.001 cubic meters, which is obtained by multiplying the dimensions of 0.01m x 0.01m x 0.01m.

2.3.5 Thermal Conductivity

The study utilised the Thermal Conductivity of Building Material Apparatus (Model: HE 110) located at the Building Services Engineering Technology Laboratory at UTHM Pagoh campus to conduct the thermal conductivity test. The thermal conductivity of the sample was measured following ISO 8302:1991. and ASTM C177 standards. This was done by measuring the heat rate needed to maintain a constant temperature on the hot plate after the temperature of the cold plate was controlled using a chiller, and steady-state conditions were achieved. The sample used in this investigation has a square shape with dimensions of 300 mm x 300 mm and a thickness of 10 mm. The hot plate was maintained at a constant temperature of 50 °C throughout the experiment.

3. Results and Discussion

The data analysis and results from the laboratory tests are reported in this chapter. To ensure clear comprehension and detailed elaboration, all collected data were presented using tables and graphs. This method of presentation facilitated the analysis and conclusions drawn to meet the goals of this bachelor's degree project. The test and analysis results discussed in this chapter focus on density, compressive strength, and thermal conductivity. Using tables and graphs allowed for a more effective and visual representation of the data, making it easier to identify trends, patterns, and correlations. This structured approach helped ensure that the project objectives were thoroughly addressed and substantiated by empirical evidence.

3.1 Trial Proportion

Table 2 *Trial Proportion (Ratio 3:1:1)*

Mix No.	Cement	Sand	Sawdust (%)	Pumice	W/C	Sample	Picture
0SD	3	1	0		0.5	6	
25SD	3	0.75	0.25	1	0.5	6	
50SD	3	0.50	0.50	1	0.5	6	

75SD	3	0.25	0.75	1	0.5	6	
100SD	3	0	1.00	1	0.5	6	

3.2 Density

The dry density of lightweight concrete filled with sawdust and pumice were measured after 24 hours based on 100mm cubes. The density of the LWC is reducing when the percentage of sawdust increases.

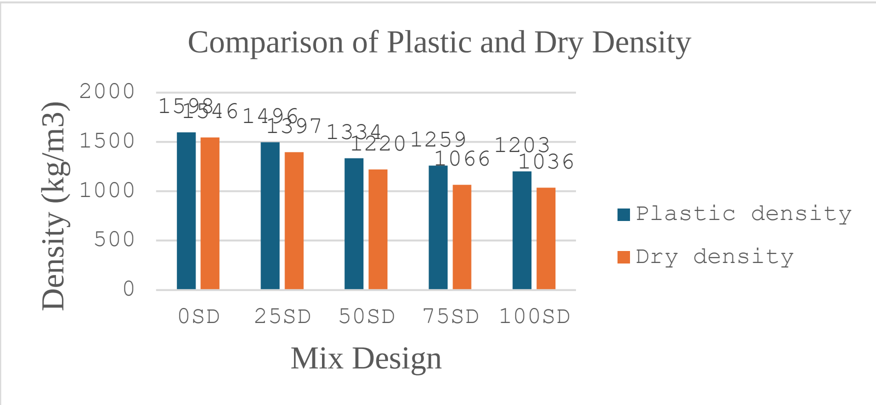

Fig 6 *Comparison between plastic density and dry density of concrete*

Based on Fig 6, both plastic and dry densities decrease as the percentage of sawdust increases. This is expected because sawdust is less dense compared to the typical materials used in the mix, leading to reduced overall density. Sample 25SD achieved the highest plastic and dry densities with containing 25% of sawdust in the concrete mixture. Meanwhile, 100SD achieved the lowest plastic and dry densities with highest percentage of sawdust. The incorporation of sawdust decreases the density of the material, which could be beneficial in applications where lightweight properties are crucial. However, it may also affect the mechanical properties, such as strength and durability. The graph clearly indicates that as the proportion of sawdust increases in the mix, both plastic and dry densities decrease. While this can be advantageous for producing lighter materials, it is essential to balance the proportion of sawdust to maintain the desired mechanical properties for practical applications. Further testing and analysis would be necessary to determine the optimal mix design for specific uses.

3.3 Compressive Strength

The different percentages for sand replacement with sawdust were used in concrete mixture to make a comparison in compressive strength of concrete sample to achieve the optimum percentage of sawdust. The compressive strength test were done based on ASTM C39 using Universal Testing Machine (UTM) for cube concrete. Figure 7 shows the data obtained for the test that done with concrete cube aged 7 and 28 days.

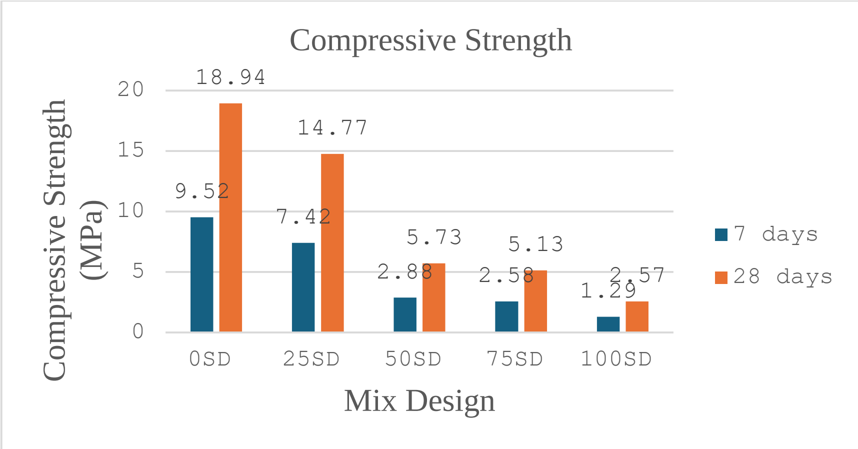

Fig 7 *Compressive Strength of LWC*

Based on experimental observed concrete with the replacement up to 25% achieved higher compressive strength other than control mix. The compressive strength of LWC filled with sawdust is reducing when the percentage of sawdust increases. Mix 25SD performs moderately but decisively lower than mix 0SD in both the initial and final compressive strength. Mix 25SD may be used in applications where moderate strength is sufficient. Moreover, from the result, it shows that to achieve the minimum compressive strength, at least 25% of natural fine aggregate must be replaced by sawdust. Using sawdust as a partial replacement in concrete can be beneficial for non-structural elements where lower compressive strength is acceptable. It indicates potential for lightweight concrete applications or eco-friendly materials where high strength is not critical. In summary, while adding sawdust to concrete mix designs reduces compressive strength, it might be advantageous for specific applications requiring lower strength and for sustainable building practices. Using the mixed designs with lower percentages of sawdust 25SD might strike a balance between strength and sustainability.

3.4 Thermal Conductivity

Thermal conductivity was tested by Thermal Conductivity of Building Materials Apparatus (Model: HE110). Thermal Conductivity test was conducted to determine thermal conductivity value of the LWC that has sawdust replacement with ratio with 25% and 75%. The thermal conductivity of the sample was measured following ISO 8302:1991. and ASTM C177 standards. The result was recorded in Table 2.

Table 3 *Thermal Conductivity*

Mix	Heat flow density, q (W/ m2)	Hot Plate Temperature, T_h (°C)	Cool Plate Temperature, T_c (°C)	Thermal Conductivity, k (W/m °K)	Heat Transfer Rate, q (W)	Thermal Resistance R_{th} (°C/W)
25SD	81	57.6	29.4	0.319	80.96	0.348
75SD	86	68.4	29.4	0.245	86	0.454

$$\text{Thermal conductivity, k} = -\frac{qx}{A(T_2-T_1)}\ [\text{W/mK}] \quad (1)$$

From Table 2 and eq 1, the thermal conductivity for 25SD is 0.319 (W/m°K) for sample which is 25% additive of sawdust fibre. Lastly for 75% of sawdust, the thermal conductivity is 0.245(W/m°K). The thermal conductivity of conventional concrete typically falls within the range of 1.0 to 1.5 W/mK. Therefore, the 75SD mix has better insulating properties. Higher thermal resistance in 75SD supports its better insulating property, meaning it resists heat flow more effectively compared to 25SD. sawdust is known for its excellent thermal insulating properties. By incorporating 75% sawdust into the lightweight concrete mix, we can significantly enhance the overall insulation of the walls. This becomes especially crucial in non-load bearing walls where maintaining a comfortable indoor temperature is essential. The reduced thermal conductivity value of 0.245 W/m°K ensures that the walls effectively resist heat transfer, leading to improved energy efficiency within the structure.

4. Conclusion

The study aimed to determine the ideal proportion of lightweight concrete filled with sawdust and pumice by evaluating the compressive strength, thermal conductivity, and density of various mixtures. The compressive strength results showed a clear trend of decreasing values as the percentage of sawdust increased: 0% sawdust mix had the highest compressive strength of 18.94 MPa, while the 100% sawdust mix had the lowest at 2.57 MPa. In terms of thermal conductivity, the values also varied across the different mixtures. The 25% sawdust mix had a thermal conductivity of 0.319 W/m°K, which decreased to 0.245 W/m°K for the 75% sawdust mix. This indicates that incorporating sawdust into the lightweight concrete mixture can lead to improved thermal insulation properties. Furthermore, the density of the lightweight concrete decreased as the percentage of sawdust increased. The 0% sawdust mix had a density of 1546 kg/m3, decreasing to 1036 kg/m3 for the 100% sawdust mix. This decrease in density with higher sawdust content suggests a potential for creating lightweight structures with enhanced thermal properties. Overall, the findings underscore the importance of the proportion of sawdust and pumice in lightweight concrete in influencing its physical and thermal properties. The study's detailed analysis provides valuable insights for future research and practical applications, offering opportunities to tailor lightweight concrete mixes to meet specific project requirements for both structural strength and thermal performance.

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