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DENSITY, COMPRESSIVE STRENGTH, AND IMPACT OF SEAWATER ON UNTREATED TIMBER-FOAMED CONCRETE AS A FLOATING MECHANISM

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ABSTRACT

Land shortages and rising sea levels are now being addressed by floating architecture. Studies on lightweight concrete as a suitable building material for structures on the water have been conducted. Therefore, this article focuses on the addition of untreated timber husk to lightweight concrete (foamed concrete) to diversify and sustainably produce construction materials. This study was designed to examine the durability and buoyancy of untreated timber husk as an addition to foamed concrete as a building material for floating architecture through an experimental approach fixed with numerical analyses on the specification and qualities of lightweight. The results of the quantitative method demonstrated that it was possible to build floating timber-foamed concrete using samples that range in density from 437.5 to 993.3 kg/m³. Each model's compressive strength was measured over a range of curing times, with TH05 producing the highest readings of 2.27 MPa and 0.89 MPa after submerging in seawater. The impact rate from saltwater towards the strength was highest at TH10 with only a 0.25 MPa difference, and the surface of each concrete showed the most reaction on TH15, which was also used to analyse the buoyancy of samples over time. To determine the effects of seawater overtime on the density and strength of timber-foamed concrete, further analysis of seawater's influence shall be conducted to enhance the materiality of floating architecture.

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Keywords: *Density, Durability, Floating Mechanism, Timber-Foamed Concrete, Seawater Impact*

INTRODUCTION

Rapid population growth has threatened the climate, and has caused sea levels to rise daily due to global warming and ice sheet melting. According to Moon (2011), climate change and a lack of useable land, particularly in urban areas, are expected due to humans' never-ending expansion, resulting in rising sea and river levels. Innovative floating architecture is thus developed as a doable attempt to deal with the effects of rising sea levels and a lack of available land. Multiple mechanisms are used to construct floating structures on top of airy or light materials. However, Olutoge and Amusan's (2014) research demonstrated that the corrosive process toward the material would generate a relatively continuous response, reducing the material's performance.

One of the most widely used building construction materials is lightweight concrete, a porous composite material considered diverse and universal. Despite the lower density of the particles, this material has demonstrated greater characteristics than conventional concrete. However, this material is prone to corrosion due to exposure to the sea and other surroundings, which reduces its durability and contaminates the sea. In addition, the chemical processes in the seawater reacted with the concrete particles, and corrosions occurred, making the substance more brittle and, ultimately, shortening the lifespan of the concrete itself.

Habibi (2015) claims that there are numerous design processes and approaches for floating architecture. Appropriate techniques and materials for creating a building that can float require in-depth process and experiment testing, and lightweight concrete is a well-known approachable material for floating facilities. However, Olutoge and Amusan's (2014) comparison research revealed the problem of continuous exposure to chemical deterioration, which will subsequently damage its physical shape and qualities. The investigation demonstrated that concrete material above high tide is more prone to cracking and corrosion than compared to concrete samples from submerged concrete or at ordinary tide levels.

Therefore, this paper highlighted the research on untreated timber husk incorporation in foamed concrete with various combination percentages, particularly for building materials. Furthermore, as a floating mechanism, the density, compressive strength, and impact of seawater on timber-foamed concrete was evaluated further in the paper.

LITERATURE REVIEW

This study emphasizes the foamed concrete for floating architecture. Therefore, the literature review highlighted the foamed concrete as lightweight concrete and is suitable for a floating mechanism. Besides, the compressive strength of foamed concrete, and the chosen aggregates to be mixed with the concrete mixture made it for floating architecture.

Floating Architecture

Floating architecture is a concept known as aquatecture. It is defined as the architecture associated with the water element, either as a symbolic, practical, therapeutic, leisure, or visual context (Wylson, 2013). Aquatecture is derived from the merging of water and architecture and relates to the building typology and adaptive reuse of approaches that can mitigate and manage sea and river rise-related threats (Williams, 2009).

Foamed Concrete

According to Amran et al. (2015), foamed concrete is a light cellular concrete that can be classified as lightweight concrete with a density of 400 – 1850 kg/m³. Ideally, it is lightweight concrete with air voids made from the foaming agents in the concrete mixture. As a result, this building material holds low density with better flowability and minimal use of aggregates (Shah et al., 2021). Thus, it is well-known as more economical than conventional concrete. Furthermore, based on Bribian et al. (2011), foamed concrete is better at perceiving aggregations, considering that the construction industry is one of the primary users of non-renewable resources, which is sand.

In addition, with the possibilities of lower density produced by foamed concrete, structural dead loads, foundation size, labour, transportation, and cost operation, all of these are deemed to be reduced with the usage of foamed concrete (Amran et al., 2015). Foamed concrete could be a partition or light load-bearing wall in high-rise and residential buildings as it is reliable enough to withstand the load (Othuman & Wang, 2011).

This study examined the influence of concrete foam as a building material on floating architecture. Foam concrete is defined as cement paste or mortar that is classified as lightweight concrete. This invention uses air-void in cement compositions using selected foaming agents (Ramamurthy et al., 2009). Hence, this make it an ideal material for a floating building. With enhanced technology and exploration, the concrete foam has been studied widely with different aggregations to produce better building materials based on its material properties (physical, chemical, and mechanical components).

Compressive Strength of Foamed Concrete

Compressive strength is one of the most crucial properties of concrete, as it indicates the excellent quality of the building material. Compressive strength is the capacity of the building material to withstand loads and compressions. According to Harith, I. K. (2018), foamed concrete has a wide range of compressive strength reading between 1 – 25 MPa. The higher the reading of compressive strength, the better the quality of the concrete as a building material. However, due to the specification of the density reading, compressive strength will be restrained, and the strength depends on the level of density. Lower density will give a lower strength reading.

Density of Foamed Concrete

Density is one of the building material's properties used to study the buoyancy and reaction of the building materials toward the water. Table 1 shows that the best concrete foam to float on seawater is the one with the lowest density, given that all readings below 1000 kg/m^3 shall float on seawater.

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Table 1. Tabulation of Finding on Density Relation towards Seawater

No.	Author	Methodology	Findings
1	Jahagirdar (2021)	Precedent studies	1. Density affect spaces allowed within the structure of form and influence design 2. Concrete is a heavy material with low density, which is great for floating architecture.
2	Nagel (2018)	Experimental and sample testing	1. Density of concrete foam usually varies (400 kg/m³ - 1600 kg/m³). 2. Density of water is 1000 kg/m³. Concrete foam shall have a density lower than 1000 kg/m³ to float.
3	Mydin et al. (2015)	Experimental and sample testing	1. Density of concrete should be less than 1000kg/m³ to float on the water surface.

(Source: Author)

Construction Waste Material as Additive in Foamed Concrete

Construction waste is the single most outstanding waste stream in Malaysia. The waste from construction is mostly generated during the design and construction process (Saadi, N., Ismail, Z., & Alias, Z., 2016). This construction waste is generated by a few factors, including the design, management workers, site condition, procurement, and external factors (Nagapan et al., 2012). Despite several government policy measures addressing the problem, sustainable resource and waste management on the job site remain a low priority for most contractors (Begum, 2009). The articles chosen for this study were based on the case of studies in Malaysia within the publication year range of 2010 – 2022. Most reports showed timber as significant construction waste material, while, other materials such as tiles and glass showed minor waste production. Table 2 shows the list of construction waste based on past studies.

Table 2 Types of Construction Waste and the Percentages of Construction waste material obtained from Literature Review

No.	Author	Construction Waste Material	
1	Fauzi et al. (2021)	timber (49.2%), concrete (36.5%), bricks (8.3%), metal (4.6%), roofing material (0.8%),	packing products (1.3%), plastic (0.6%), glass and ceramic (0.4%)

2	Zainun et al. (2016)	mix waste (54.3%), concrete (20.0%), tiles (8.4%), brick and concrete (5.0%), timber (4.1%), tiles and concrete (1.9%), iron (1.8%),	road pavement (1.5%), brick (1.2%), gypsum board (1%), sand (0.5%), glass (0.03%)
3	Foo et al. (2013)	timber (49.0%), brick (21%.0), packaging (21.0%),	concrete (7.5%), steel (2.5%)
4	Nagapan et al. (2013)	timber (58.7%), packaging (15%), bricks (14%),	concrete (5%), mortar (4%), metals (3.3%)
5	Nagapan et al. (2012)	timber (69.10%), concrete (12.32%), metals (9.62%),	bricks (6.54%), others waste (2%), plastics (0.43%)
6	Masudi (2011)	timber (45.5%), rebar (9.6%), concrete (4.3),	bricks (3.0%), plaster (1.8%), tiles (1.4%)

Based on the research analysis, timber waste from construction offers a suitable material for a mixture of lightweight concrete due to its percentage of waste produced and sustainability. These waste materials are forcing environmental problems globally; thus, their environmental impact can be countered by reusing the waste produced. Müller and Frangi (2021) stated that timber and concrete combine the benefits of both materials and provide a practical response to the growing need for sustainable building. Findings from the incorporation of timber with concrete for structure demonstrate extremely high stiffness and great shear resistance as a composite slab (Müller and Frangi, 2021). With the different percentages of additives incorporated in concrete, the properties of its final product will differ. Therefore, it is most relevant to take timber waste as the additional aggregate for the foamed concrete to study its density and compressive strength for floating structures.

Impact of Seawater towards Lightweight Concrete

Foamed concrete material has significant exposure to seawater and its nature. From Lv, H., Chen, J., & Lu, C. (2021), concrete corrosion occurs when the concrete structure is exposed to seawater facing a sulphate attack, reducing the durability of concrete. The impact of seawater is often related to metal; however, concrete corrosion can occur due to the corrosive environment, thus deteriorating the properties. Concrete exposed to seawater will cause a chemical attack, affecting the concrete's properties (Yang & Luo, 2012). According to Yang & Luo (2012), the deterioration process is caused by the complex biological attack process involving the movement of ions in the concrete mixture and chemical reaction from the sulphate ions towards the other ions. Therefore, the corrosion rate of concrete is measured to determine how the chemical attacks affect different aggregations of the foamed concrete and the properties of each sample after exposure to the seawater. Tabulation data of the condition of foamed concrete is taken and shown in Table 3.

Table 3. Literature Reading of Corrosivity Impact Towards Lightweight Concrete

No	Author	Methodology	Findings
1	Cheng et al. (2018)	Experimental and sample testing	1.Concrete exposed to seawater will cause deterioration in the aggregates (chloride-induced corrosion).
2	Guo et al. (2018)	Experimental and sample testing	1.Compressive strength is affected by exposure to seawater
3	Olutoge & Amusan (2014)	Comparative studies, experimental and sample testing	1.Chemical corrosion will happen once the concrete is immersed in seawater. 2.Concrete exposed above the tide is more likely to get vulnerable to corrosivity.
4	Yang & Luo (2012)	Comparative studies, experimental and sample testing	1.Concrete with better compressive strength has greater resistance toward the sulphate attack of seawater 2.An optimal sulphate attack has a good impact on the concrete. Excessive exposure will cause severe effects over time

METHODOLOGY

Quantitative methods - experimental and laboratory testing were used in this study to analyse the result further. The study incorporated untreated timber as an additive into the foamed concrete mixture. Timber-foamed concrete cube samples wouldl be made and developed using the timber husk into the foamed concrete, with the different percentages of timber husk as the parameters to study the properties of the foamed concrete. Below are the parameters set for the experiment:

Manipulated variables: Percentages of timber husk in the foamed concrete mixture (0%, 5%, 10%, 15%).
Fixed variables: Dimension of concrete blocks (10cm x 10cm x 10cm) and protein-based foaming agent (Noraite PA-1).
Responding variables: Density (kg/m^3) and compressive strength (MPa) of timber-foamed concretes on different curing periods and after submerged in seawater.

An experimental method was taken to test the timber-foamed concrete and to analyse the impact of the timber husk additives on the foamed concrete properties. Engineering parameters, including the density using a weight scale and compressive strength using an Automatic Compression Testing Machine. During the curing periods and after being submerged in seawater, the foamed concrete were measured using different percentages of timber husk amount in the concrete mix.

Preparation of Materials

The materials were initially set up and prepared to make the timber-foamed concrete mixture, as shown in Figure 1. Coarse untreated mixed timber husk waste was collected from a timber factory in Kedah. The dimension of the coarse timber husk was within the range of 0.3 cm – 1.0 cm in length and 0.2 cm – 0.5 in width. Coarse timber husk was used as part of the foamed concrete mixture for the experimental procedure, as shown in Figure 1(a).

Preparation of the Untreated Timber-Foamed Concrete Mixture

The experiment involved testing concrete cubes (fixed dimensions of 10cm x 10cm x 10cm) for 7 days, 14 days, and 28 days of curing, as well as after the curing period when the concrete cubes submerged in seawater for another 28 days. The 28-day curing period was chosen as this was the most stable state of concrete, showing the best compressive strength and was ready to be built. The aggregations of the foamed concrete mixture

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involved the usage of different ratios of timber husk (from construction waste material), where 0% of timber husk (control sample), 5% of timber husk, 10% of timber husk, 15% and of timber husk was incorporated. Standard foamed concrete blocks made with a typical mixture was also made as a control sample to compare the concrete cubes after testing.

Figure 1. Preparation of Material and Foamed Concrete Mixture
(Source: Author)

As materials to produce untreated foamed concrete were prepared, the fine sand and cement were first sieved through a 1.18mm sieve tray and allowed to dry for a day. After fine sand and cement were well dried, the components were mixed dry; water was added in stages to ensure the mixture was mixed thoroughly. The water-cement ratio in the design was used based on the ratio of 1:2:0.5 (cement: fine sand: water). After the concrete mixture was mixed completely, the coarse timber husk was added to the foamed concrete mixture based on the calculated percentage after the concrete was mixed. Then the untreated timber husk was incorporated inside the mix, protein-based foaming agent (Noraite PA-1) (as shown in Figure 1(b). Later wasadded to the actual mortar density (weight of foam agent is 47-50% of the mortar density). To produce the foam, Portafoam PM-2 was used as the foaming generator, transforming the liquid chemical into stable foam. For every 1 litre of foaming agents, 35 litres of water was mixed into the foaming agent to dilute it before generating the foam with an expansion rate of 13.8 times. Foam was then added to the mixture and allowed it to be incorporated well with the mixture.

As this study aims to create foamed concrete that can float in water, the targeted density of each sample shall be below 1000kg/m3. Therefore, when the mixture was done, the density of the wet mixture was taken and should be within the range of 900 kg/m3 -1000 kg/m3. This was to ensure that the dry-foamed concrete achieved the best density to keep it floating on seawater. Depending on the w/c ratio, density, and cellular structure obtained, foamed concrete's dry density (oven dried) was typically lower than its wet density. Table 4 shows the details of the concrete cubes made for testing.

Table 4. Concrete Cube Details for Each Sample

Sample	Percentage Of Timber Husk, %	Wet Density, kg/m^3	Volume, cm3	No Of Cubes
1	0	860.0	1000	16
2	5	873.0	1000	16
3	10	936.0	1000	16
4	15	975.5	1000	16
			Total Specimen Cast	72

(Source: Author)

After a mixture of timber-foamed concrete was done, as shown in Figure 1(c), sample blocks were poured into the fabricated mould (fixed size of 10cm x 10cm x 10cm). The samples were then left overnight and were demoulded the next day and then wrapped with cling wrappers, and left to air dry for the curing process. The samples at each curing period were then taken and subjected to 24 hours of oven drying and kept cool to reach normal room temperature (23 to 26°C) before the testing.

Laboratory Experimental Methodology

The experiments included numerical studies and first-hand data analysis. As shown in Figures 2(a) and 2(b), the mass and compressive strength of each sample were taken. To test the density of each cube, the mass of the cubes was taken and recorded and divided by the volume (1000 cm^3) respectively. To test on the compressive strength, a GOTECH GT-7001-BS300, a closed-loop servo-hydraulic dynamic of 300 tan-capacity machine was used. Samples were put in the space provided and the readings were shown upon testing. Testing was done every 7th, 14th, and 28th day of the curing period. Density and compressive strength were compared during the curing period and after the impact of seawater occurs. In addition, seawater was collected in Gelugor, Pulau Pinang, for the test. The cubes submerged in seawater solution to check their buoyancy (Figure 2 (c)) after the curing

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period to see the impact of the seawater. After that, samples were left in the seawater, and a compressive strength test was taken. The samples were left immersed in seawater for only 28 days due to time constraints. After the cubes submerged in the seawater, the observation on the surface of each cube was made to see the impact of seawater on the cubes (cracking effect and particles shown on the surface) before compressive strength testing took place.

a)Mass measuring b) Compressive strength c) Testing in seawater

Figure 2. Testing Method on Untreated Timber-Foamed Concrete

(Source: Author)

RESULTS AND DISCUSSIONS

Density

As the research aims to create a material that functions optimally as a floating mechanism, the density for each sample must meet a specific density requirement to ensure the cubes can float in seawater. For foamed concrete, the density usually varies in the range of 400 kg/m³ - 1600 kg/m³, and it depends on the percentage of the foaming agent incorporated in the concrete mixture (Mydin et al., 2015).

Figure 3 below shows the density of the concrete mix obtained for each sample during different curing periods. The density of all samples shows a reading below 1000 kg/m³. Thus, the samples proved that these materials float when submerged in seawater. The highest density reading during the curing period for all samples was 28 days, while the lowest reading showed only on day 8.

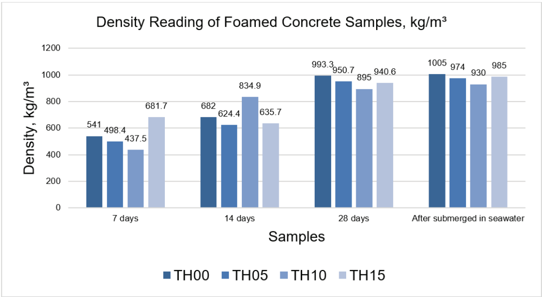
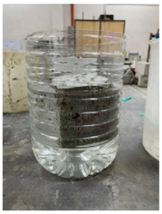


Figure 3. Reading Shows the Density of The Timber-Foamed Concrete.
(Source: Author)

Meanwhile, after submerging all the samples in seawater, the density reading increased for each sample as the foamed concretes were porous and quickly absorbed water. The result indicates that the density of timber-foamed concrete increased with time. Figure 4 shows the buoyancy of concrete samples during the 28-day curing period in seawater. The results showed that all the samples can float in seawater. However, TH15 has the shortest ability to float in seawater (6 minutes), while other samples managed to float in seawater within the range of 10 - 18 minutes. This might be due to the over-amount of timber husk, as timber properties readily absorb water.




a) TH00 b) TH05


c) TH10 d) TH15

Figure 4. Testing of Buoyancy of Samples into Seawater
(Source: Author)

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Compressive Strength

The compressive strength of timber-foamed concrete was done to see the compressive strength and to define its capacity to withstand the loads as a building material.

Figure 5 shows the reading of the compressive strength for each sample during and after the curing periods ended – submerged in seawater. The highest compressive strength produced was during the 28-day curing period. Thus, the reading proves that compressive strength increases as the curing periods increase as the cubes have reached their stable state of the concrete properties. The highest reading of compressive strength was produced when 5% of timber husk was combined in the foamed concrete for 28 day curing period (2.27 MPa). The lowest reading of compressive strength during the same curing period was the foamed concrete with 15% of timber husk mix, which only produced 0.27 MPa.

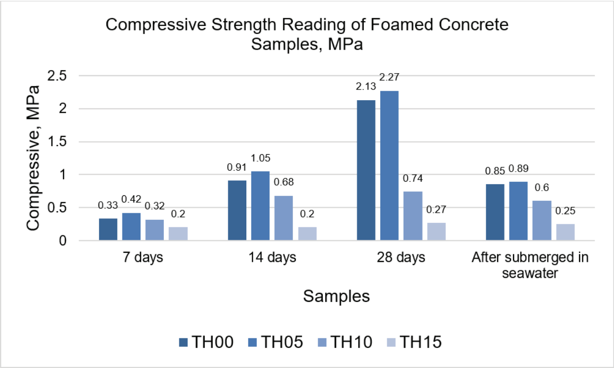

Figure 5. Reading of Compressive Strength for Each Timber-Foamed Concrete Mixture

(Source: Author)

Therefore, the above result shows that mixing timber husk into foamed concrete would increase the compressive strength to a certain percentage. This can be seen clearly that TH05 produces greater compressive strength than the standard foamed concrete, TH00. Nevertheless, different ratios of timber husk mix proved that there is a limit to the amount that could help increase the strength of the foamed concrete.

However, as the samples submerged into seawater, the reading of compressive strength decreased, and the highest impact rate towards seawater was TH00 and TH15. In addition, the difference from 28 days curing period was 1.28 and 1.38 MPa, respectively, as shown in Figure 6. TH10 and TH15 showed minor differences in reading from the curing period, indicating that seawater's impact occured more to TH00 and TH05.

Readings on compressive strength after testing with seawater showed that the compressive strength decreased after submerging in seawater.TH05 had the highest difference in reading after been submerged in seawater. However, the reading of compressive strength for TH05 was the highest after being submerged in seawater, with a reading of 0.89MPa.

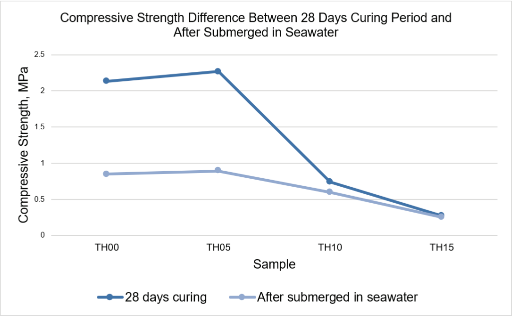

Figure 6. Relation of The Compressive Strength Between 28 Days of Curing and After Samples Submerged into Seawater

(Source: Author)

Impact Towards Seawater

Exposure between concrete and seawater will cause a chemical attack, affecting the concrete's properties (Yang & Luo, 2012). According to Yang and Luo (2012), the deterioration process was caused by the complex process of the natural attack involving the movement of ions in the concrete mixture and chemical reaction from the sulphate ions towards the other ions. Therefore, analysis of the surface of samples after seawater exposure was taken, and the impact of the concrete was measured to determine how the chemical attacks affect the different aggregations of the foamed concrete after exposure to the seawater. Tabulation data of the condition of foamed concrete was taken and shown in Table 5.

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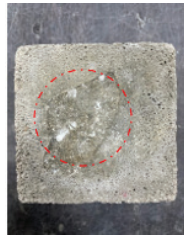
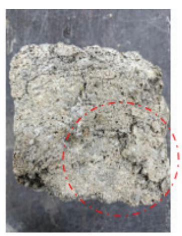
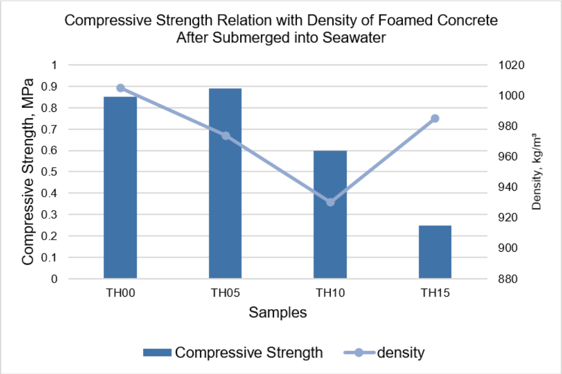
Table 5. Impact of Seawater Analysis on the Surface of Samples

Impact of Seawater			
Sample	Test	Conditions	
TH00	Seawater		
TH05	Seawater		
TH10	Seawater		
TH15	Seawater		

Label: Cracking or white residue showing the impact of seawater.
(Source: Author)

From the analysis based on the surface of the samples in Table 5, TH15 shows the impact from seawater by observing the surface area of the cube. This could be seen when there were more reaction on the surface with white particles and major cracking on the surface area. The seawater reacted towards TH15. The most as observed was a white precipitate on the surface of the cube. It shows that the ion attack occured on the cube samples. As Mangi et al. (2019) mentioned, most concrete structures are partly or exclusively situated to seawater and sometimes exposed to the atmosphere. The saltwater will get deposited in the concrete pores, and as it dries up from the exposure to the atmosphere, the water will crystallize into salt particles, which is when the concrete disruption occurs. When the white residue occurred on the surface of samples, cracking took place along the way due to the interference from chemical decomposition.

Based on the experiment made after samples were submerged into seawater, Figure 7 shows that TH05 had the best ability and compressive strength (0.89MPa). Nevertheless, TH10 and TH15 showed lesser impact on the seawater impact. Thus, the difference in strength reading during the curing period and after being submerged in seawater was lesser compared to TH00 and TH15. As timber is well known to absorb water, the result showed that the higher the coarse timber husk content in the sample, the higher the density after submerging in seawater as it absorbed more water.



(Source: Author)

Figure 7. Relation of the Compressive Strength Towards the Density of Sample After Submerged in Seawater

Compressive Strength Relation with Density of Untreated Timber-Foamed Concrete

Figure 8 shows the density's relation to each sample's compressive strength during the 28-day curing period. Based on Figure 8, the optimum amount of the timber husk was 5%, indicating a low density (950.7 kg/m³) with the highest compressive strength reading (2.27MPa). This proves that timber husk aggregation for foamed concrete was better than the standard foamed concrete as timber husk. It acted as a stronger binder and was more tensile, producing higher density reading with lower compressive reading. However, a higher percentage of untreated timber husk in the mixture decreased the compressive strength reading, as shown I n TH10 and TH15 might be due to the composition of timber husk as the binder of the foamed concrete.

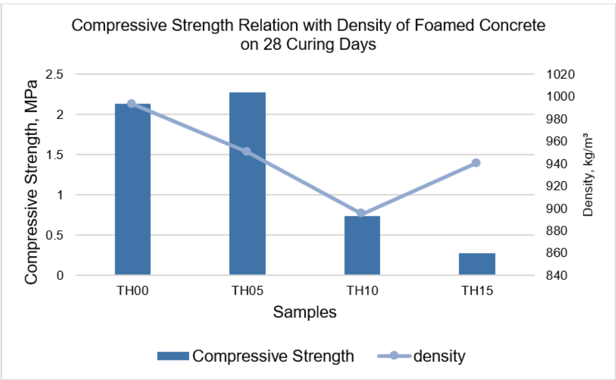


Figure 8. The Relation of The Compressive Strength Towards the Density of Sample on the 28 Days Curing Period

(Source: Author)

CONCLUSION

The research showed that domestic construction waste (untreated timber) is a reliable material as a foamed concrete additive. However, there is an optimum amount and percentage of the timber husk to be incorporated into the foamed concrete mixture that will give the best compressive strength reading and minor seawater impact towards the timber-foamed concrete. Based on the experiment conducted, foamed concrete with 5% untreated timber shows the best compressive strength. Nevertheless, more experiments of timber as foamed concrete additives can be done to ensure the fulfilment of the ACI 213R (greater than 17MPa) to produce a structural mechanism. Apart from that, the findings showed that timber-foamed concrete can create the proper density as a floating mechanism in architecture. Despite the compressive strength reading, samples displayed results where the density reading is below 1000 kg/m^3,. Due to time constraints and a longer testing period, the impact after study paper. Further analysis of the timber-foamed concrete and its properties after submerging in the seawater should be done with better probes and accelerated methods to reduce the timeline of the experiment on the impact of concrete. In addition, suggestions on other waste materials can also be incorporated into foamed concrete for further study. This may involve waste that is more water resistant or using treated timber for foamed concrete.

In a nutshell, the research shows that improvisation of the foamed concrete as a floating architecture. As floating architecture is now recognizable, this study shall be an initiative to enhance the building material towards a better and greener material, thus helping future generations in the building and construction environment.

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AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research, the development of the experiment, and the write-up. The field experiment, data cleaning and tabulation were undertaken by researchers in the School of Housing, Building, and Planning, Universiti Sains Malaysia. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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