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IeGRESAFE 2022

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"Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life"

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THE COMPRESSIVE STRENGTH AND IMPACT OF SEAWATER ON FOAMED CONCRETE WITH UNTREATED TIMBER HUSK AS ADDITIVE FOR A FLOATING MECHANISM

Mizan Adillia Ahmad Fuad[1], Zalena Abdul Aziz[2]*, Nooriati Taib[3]
***Corresponding Author**
[1,2,3]School of Housing, Building, and Planning, Universiti Sains Malaysia, Penang, Malaysia

mizanadillia@student.usm.my
*zalena@usm.my
nooriati@usm.my

Abstract

Floating architecture has become a solution to land scarcity and rising sea levels. Studies have been done on lightweight concrete as an appropriate building material for structures on water. Hence, this paper focuses on untreated timber husk as another element mixed with lightweight concrete (foamed concrete) to create diversity and sustainability for building materials. This study is made to look at different percentages of untreated timber husk as additive in foamed concrete as a floating architecture building material while looking at its durability and buoyancy towards seawater by an experimental with numerical studies on the specification and properties of lightweight. The quantitative method's finding shows that it is achievable to design a floating timber-foamed concrete, where samples offer a range of densities between 437.5 – 993.3 kg/m³. Compressive strength is tested for each model during different curing periods, and the highest reading is produced by TH05 which is 2.27 MPa and 0.89 MPa; after been submerged in seawater. The buoyancy of samples is also analysed using seawater over time, and the surface of each concrete shows the most reaction on TH15, and rate of impact from seawater towards the strength was best at TH10 with only 0.25 MPa difference. Further analysis of the impact of seawater shall be observed to see the effects of seawater on the density and strength of timber-foamed concrete over time.

***Keywords**: Corrosivity, Density, Durability, Floating Mechanism, Timber-Foamed Concrete.*

INTRODUCTION

The environment has become increasingly vulnerable due to rapid human growth and population, and global warming and ice sheet melting has caused seawater levels to rise daily. According to Moon (2011), climate changes would cause the sea and river water levels to grow, and scarcity of usable land, especially in the urban area, is anticipated due to the never-ending development by humans. Therefore, innovative floating architecture is created as an approachable initiative to counter the effect of sea rise levels and scarce land. Floating architecture is built on air-filled or lightweight material by various mechanisms. However, Olutoge and Amusan's (2014) studies prove that corrosion process towards the material will cause a relatively continuous response thus affecting the performance of the material.

Lightweight concrete is one of the most well-known building materials used for construction as it is a porous composite material known as diversified and universal. This material has shown better properties than conventional concrete, despite the lower density of aggregates. However, exposure to the sea and other environments has left this material prone to corrosion, reducing its durability and polluting the seawater. Corrosions happened as the chemical reactions in the water reacted toward the concrete aggregates, making the material more vulnerable and, in the end, reducing the life span of the concrete itself.

According to Habibi (2015), floating architecture has many design approaches and methodologies. 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. Nonetheless, comparative studies made by Olutoge and Amusan (2014) discovered the issue of exposure towards deterioration chemically, which later will affect its physical shape and properties. The studies show that cracking and corrode towards the concrete material above high tide is more impactful than at the mean tide levels or submerged concrete samplings.

This paper will highlight studies of untreated timber husk incorporate in foamed concrete with different mixture percentages, specifically for a building material. Density, compressive strength, and the influence of seawater on the timber-foamed concrete will be tested as a floating mechanism.

LITERATURE REVIEW

The paper emphasizes the foamed concrete for floating architecture. Therefore, the literature review will highlight the foamed concrete as a lightweight concrete that is suitable as a floating mechanism, compressive strength and the chosen aggregates to be mixed with the concrete mixture.

Foamed Concrete

According to Amran et al. (2015), foamed concrete is a light cellular concrete that can be classified as lightweight concrete where the density is usually in a range of 400 – 1850 kg/m³. Ideally, it is lightweight concrete with air voids made from the foaming agents in the concrete mixture. This building material holds low density with better flowability with minimal use of aggregates (Shah et al., 2021). Thus, being well known as more economical than conventional concrete. Based on Bribian et al. (2011), foamed concrete is better in perceiving the aggregations, considering that the construction industry is one of the primary users of the 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 are deemed to be reduced (Amran et al., 2015). Foamed concrete material could be a partition or light load-bearing walls in high-rise and residential as it is reliable enough to withstand the load (Othuman and Wang, 2011).

Compressive Strength of Foamed Concrete

One of the crucial properties of concrete is compressive strength, 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 (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. Due to the specification of the density reading, compressive strength, however, will be restrained as 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 buoyant and reaction of the building materials towards 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/m³ shall float on seawater.

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 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/m^3 - 1600 kg/m^3). 2. Density of water is 1000 kg/m^3. Concrete foam shall have density lower than 1000 kg/m^3 this to float.
3	Mydin et al. (2015)	Experimental and sample testing	1. Density of concrete should be less than 1000kg/m^3 to float on water surface.

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, Ismail, & Alias, 2016). This construction waste is generated from few factors including the design, management workers, condition of site, 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). Articles were chosen based on the case of studies in Malaysia within the publication year range of 2010 – 2022. Most reports show timber as significant construction waste material, and other materials such as tiles and glass show minor waste production. Table 2 shows the list of construction waste based on studies made in a few papers. From the analysis, timber waste from construction offers a suitable material for mixture with lightweight concrete due to its percentage of waste produced and sustainability. Therefore, it is most relevant to take timber waste as the additional aggregate for the foamed concrete.

Table 2
Type of Construction Waste and Its Percentages Based on 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%),	concrete (7.5%),

		brick (21%.0), packaging (21.0%),	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%)

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 happens 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. 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 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 see 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 towards the aggregates (chloride-induced corrosion).
2	**Guo et al. (2018)**	Experimental and sample testing	1. Compressive strength is affected by exposure towards seawater
3	**Olutoge & Amusan (2014)**	Comparative studies, experimental and sample testing	1. Chemical corrosion will happen once concrete is immersed in seawater. 2. Concrete exposed above the tide is more likely to get vulnerable towards corrosivity.
4	**Yang & Luo (2012)**	Comparative studies, experimental and sample testing	1. Concrete with better compressive strength has greater resistance towards the sulphate attack of seawater 2. An optimal sulphate attack gives a good impact towards the concrete. Excessive exposure will cause sever effect over time.

METHODOLOGY

Quantitative methods - experimental and laboratory testing were used in this paper to analyse the result further. The study incorporates untreated timber as an additive into the foamed concrete mixture. Timber-foamed concrete cube samples will 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 foamed concrete mixture (0%, 5%, 10%, 15%).
Fixed variables	:	Dimension of concrete blocks (10cm x 10cm x 10cm) and foaming agent (Noraite PA-1).
Responding variables	:	Density (kg/m^3) and compressive strength (MPa) of timber-foamed concretes.

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 weight scale and compressive strength using Automatic Compression Testing Machine during the curing periods and after being submerged in seawater, are measured for the foamed concrete using different percentages of timber husk amount in the concrete mix.

Preparation of Materials

The materials were first set up and prepared to make the timber-foamed concrete mixture, as shown in Figure 1. Untreated mixed timber husk waste is collected from a timber factory in Kedah. The timber waste was first collected and then shredded into two; coarse timber husk and fine timber husk where the coarse timber husk is within the range of 0.3 cm – 1.0 cm length and 0.2 cm – 0.5 width. Coarse timber husk will be used as part of the foamed concrete mixture for the experimental procedure as shown in Figure 1(a).

Preparation of the Timber-Foamed Concrete Mixture

The experiment involves testing concrete cubes (fixed size of 10cm x 10cm x 10cm) during the 7 days, 14 days, and 28 days of curing and after the curing period when the concrete cubes are submerged into seawater. The 28-day curing period is chosen as this is the most stable state of concrete where it shows the best compressive strength and is ready to be built. The aggregations of the foamed concrete mixture involved the usage of different ratios of timber husk (from construction waste material), where 0% of timber husk, 5% of timber husk, 10% of timber husk, 15% and of timber husk of timber husk will be incorporated. Standard foamed concrete blocks made with a typical mixture will also be made to set the parameter of the different mixes of concrete cubes.

Figure 1
Preparation of Material and Foamed Concrete Mixture.

a) Coarse timber husk b) Foaming agent c) Foamed concrete mixture

Table 4
Concrete Cube Details for Each Sample.

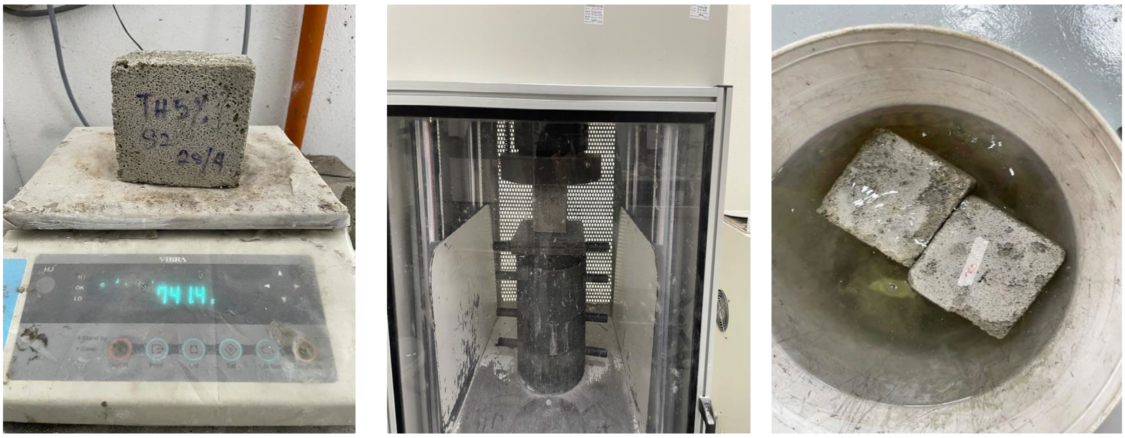
Sample	Percentage Of Timber Husk, %	Wet Density, kg/m³	Volume, cm³	No Of Cubes
1	0	860.0	1000	16
2	5	873.0	1000	16
3	10	936.0	1000	16
4	15	975.5	1000	16
			Total Specimen Cast	72

Table 4 shows the details of the concrete cubes made for testing. The water-cement ratio in in the design is used based on the ratio of 1:2:0.5 (cement: fine sand: water). The timber husk is added into the foamed concrete mixture according to the calculated percentage after the concrete is mixed. After untreated timber husk is incorporated inside the mix, protein-based foaming agent (Noraite PA-1), as shown in Figure 1(b), will be added relative to the actual mortar density (weight of foam agent is 47-50% of the mortar density). After a mixture of timber-foamed concrete is done, as shown in Figure 1(c), the wet density is tabulated, and blocks are then let to dry overnight and wrapped with cling wrappers each for the curing process. The samples at each curing period were then subjected to 24 hours of oven drying and kept cool to reach average temperature before the testing.

Laboratory Experimental Methodology

The experiments include numerical studies and first-hand data analysis. Mass and compressive strength, as shown in Figures 2(a) and 2(b), of each sample will be taken, and the cubes will submerge in seawater solution to check their buoyancy (figure 2 (c)) after two weeks to see the impact of seawater. To test on the density of each cube, mass of the cubes is taken and recorded and will be divided by the volume (1000 cm³) respectively. Testing is done every 7th, 14th, and 28th day of curing, and after the 28th day of the curing period - the samples will be submerged in seawater, and a compressive strength test is taken. Density and compressive strength will be compared during the curing period and after the impact of seawater occurs. After the cubes are submerge in the seawater, the observation on the surface of each cube is made to see the impact of seawater towards the cubes (cracking effect and particles shown on the surface) before compressive strength testing taken place.

Figure 2
Testing Method.



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

RESULTS AND DISCUSSIONS

Density

As the research aims to create a material best as a floating mechanism, the density for each sample shall 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). Table 5 shows the density of the concrete mix obtained for each sample during different curing periods.

Table 5
Tabulation Data of The Density of Foamed Concrete.

Sample	Average Density, kg/m³ Period			
	7 days	14 days	28 days	After Submerged in Seawater
TH00	541.0	682.0	993.3	1005.0
TH05	489.4	624.4	950.7	974.0
TH10	437.5	834.9	895.0	930.0
TH15	681.7	635.7	940.6	985.0

Based on Figure 3 below, the density of all samples shows a reading below 1000 kg/m³. Thus, the samples prove that these materials can float when submerged in seawater. The highest density reading during the curing period for all samples is 28 days, while the lowest reading shows on day 8. Meanwhile, after submerging all samples in seawater, the density reading increased for each sample as the foamed concretes were porous and quickly absorbing water. The result indicates that the density of timber-foamed concrete increase with time. Figure 4 shows the buoyancy of concrete samples during the 28-day curing period in seawater. Results show that all samples can float in seawater; however, TH15 has the shortest ability to float in seawater. This might be due to the over-amount of timber husk as timber properties readily absorb water.

Figure 3

Reading Shows Density of The Timber-Foamed Concrete.

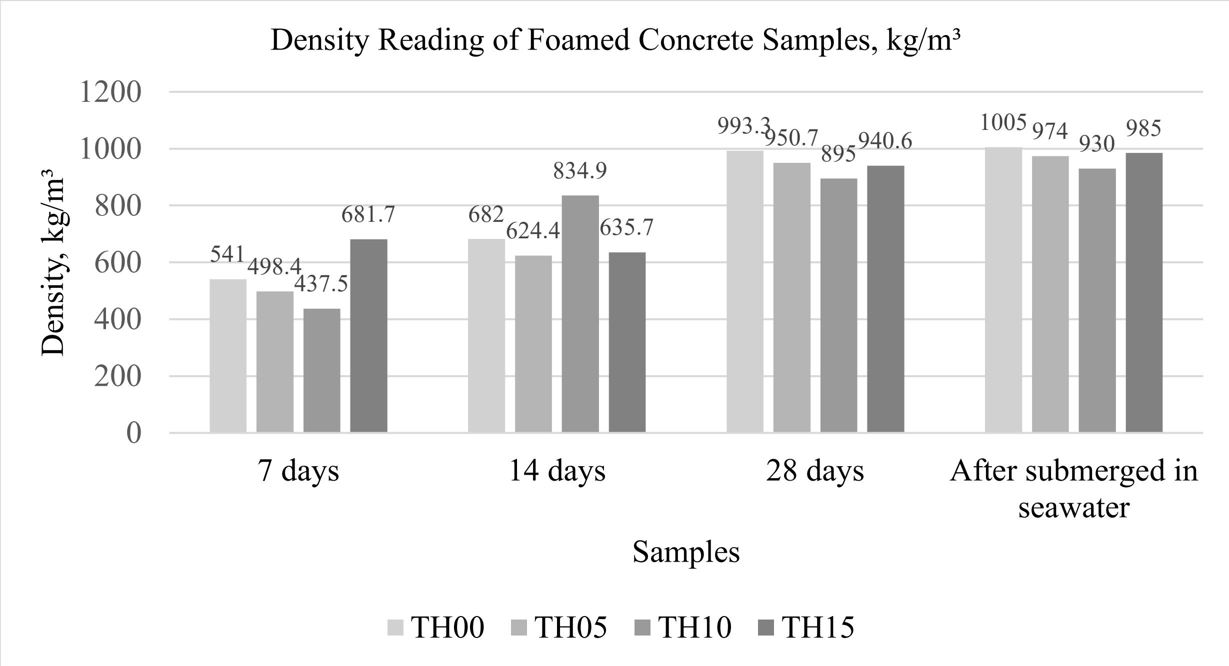


Figure 4

Testing of Buoyancy of Samples into Seawater.

a) TH00 b) TH05

c) TH10

d) TH15

Compressive Strength

The compressive strength of timber-foamed concrete was done to see the compressive strength and defined its capacity to withstand the loads as a building material. Table 6 shows the reading of the compressive strength for each sample for all curing periods and after the curing process ended – submerged in seawater.

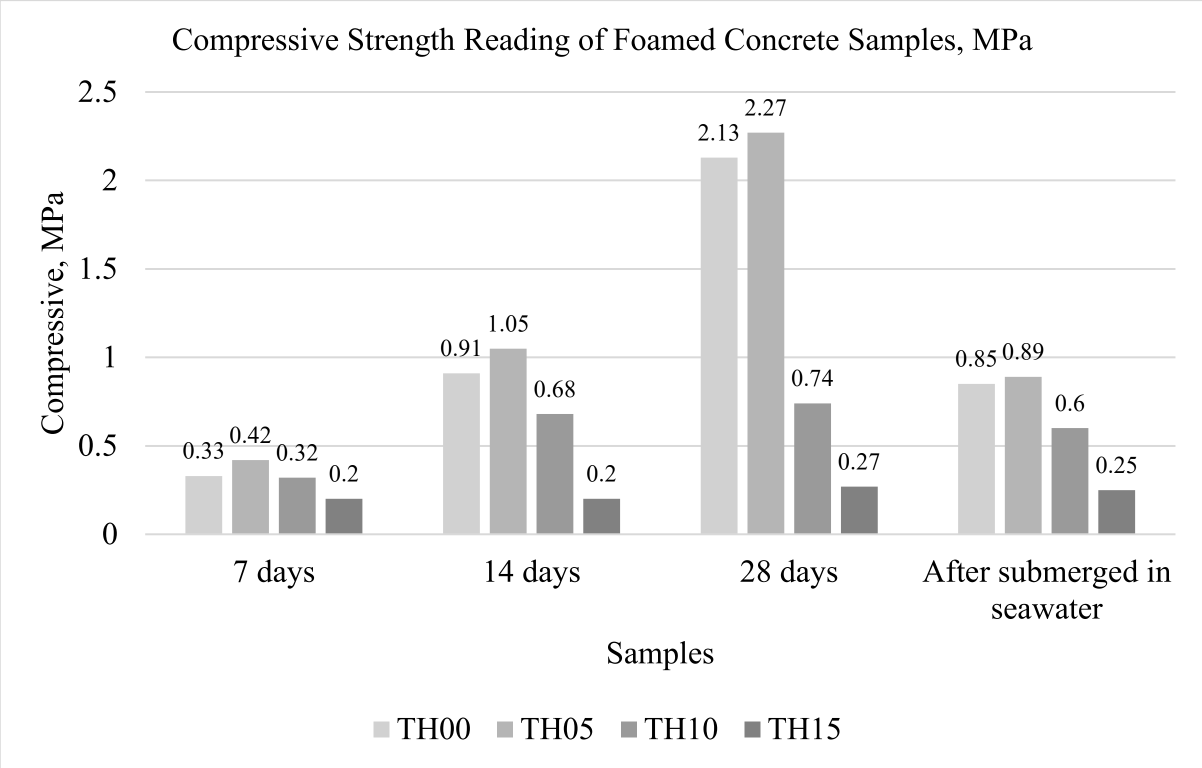
Table 6

Tabulation Data of The Compressive Strength.

Sample	Average Compressive Strength, MPa			
	Period			
	7 days	14 days	28 days	After Submerged in Seawater
TH00	0.33	0.91	2.13	0.85
TH05	0.42	1.05	2.27	0.89
TH10	0.32	0.68	0.74	0.60
TH15	0.20	0.20	0.27	0.25

Based on Figure 5, 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 has reached its 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 produces 0.27 MPa.

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

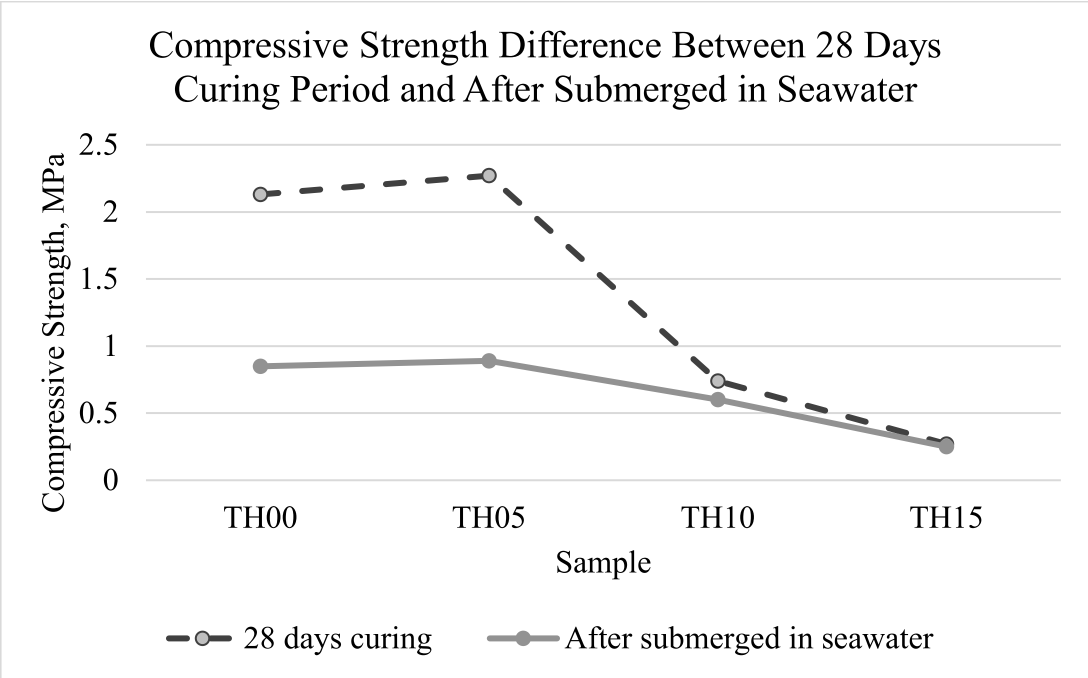


Therefore, the above result shows that mixing timber husk into foamed concrete would help increase the compressive strength to a certain percentage. This can be seen clearly that TH05 produces greater compressive strength than the standard foamed concrete, TH00. Nevertheless, different ratios of timber husk mixed prove 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, where the difference from 28 days' curing period was 1.28 and 1.38 MPa, respectively as shown in Figure 6. TH10 and TH15 show minor differences in reading from the curing period, indicating that seawater's impact occurs more to TH00 and TH05.

Readings on compressive strength after testing with seawater show that the compressive strength reading decreases after submerged in seawater.TH05 has the highest difference of reading after been submerge in seawater. However, the reading of compressive strength for TH05 is the highest after submerged in seawater with a reading of 0.89MPa.

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



Impact Towards Seawater

Exposure between concrete and 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 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 is taken, and the impact of the concrete is measured to see how the chemical attacks affect different aggregations of the foamed concrete after exposure to the seawater. Tabulation data of the condition of foamed concrete is taken and shown in Table 7.

Table 7
Impact of Seawater Analysis on the Surface of Samples.

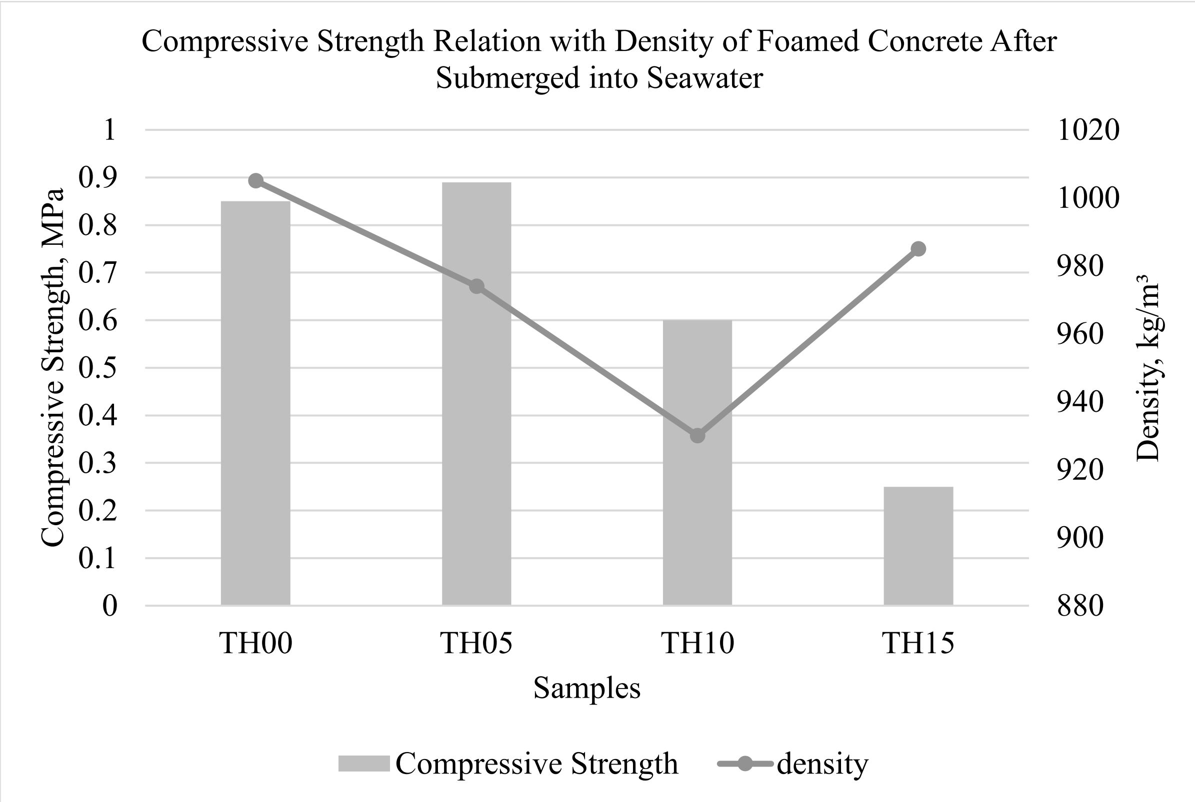
Impact of Seawater			
Sample	**Test**	**Conditions**	
TH00	Seawater		
TH05	Seawater		
TH10	Seawater		
TH15	Seawater		

From the analysis made based on the surface of the samples in Table 7, TH15 shows the most impact from seawater by observing on the surface area of the cube. This can be seen as there is more reaction on the surface with white particles and major cracking on the surface area. The seawater reacts towards TH15 the most as there is more white precipitate on the surface of cube. It shows that the ions attack occurred onto the cube samples.

Based on the experiment made after samples are submerged into seawater, Figure 7 shows that TH05 has the best ability and compressive strength (0.89MPa). Nevertheless, TH10 and TH15 show 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.

Figure 7

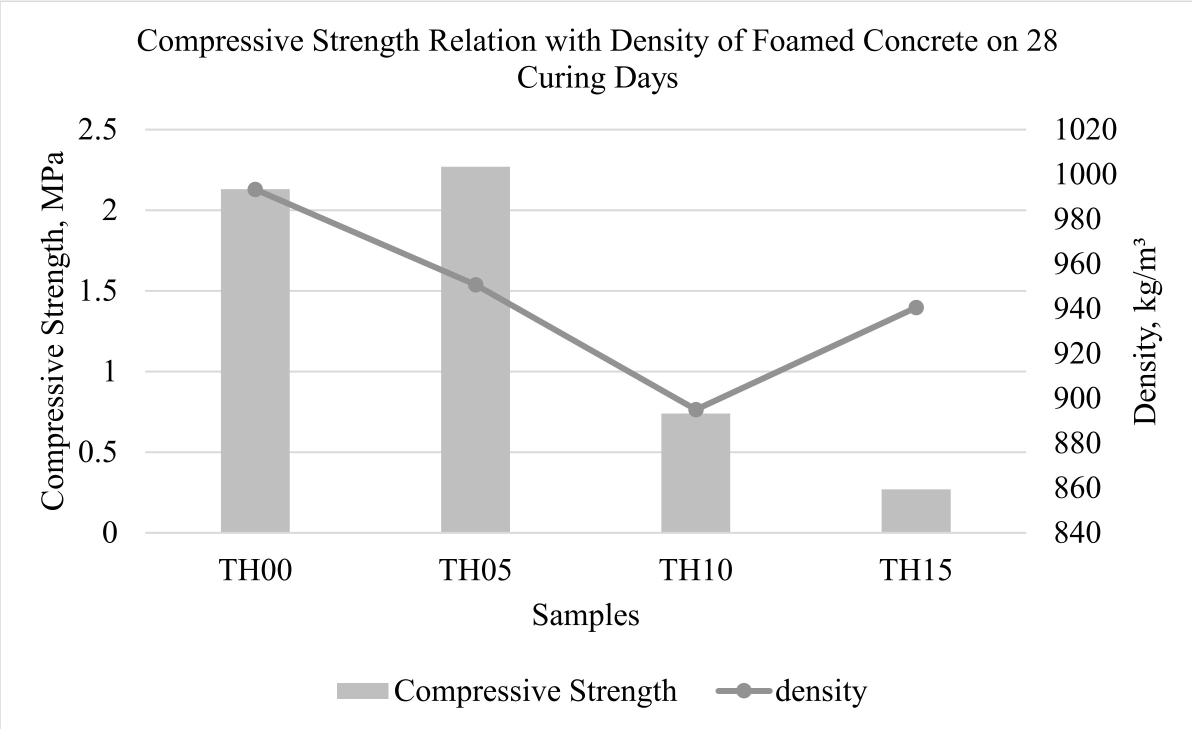
Relation of the Compressive Strength Towards the Density of Sample After Submerged in Seawater.



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 is 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 is better than the standard foamed concrete, producing higher density reading with lower compressive reading. However, higher percentage of untreated timber husk in the mixture decreases the compressive strength reading as shown on TH10 and TH15.

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



CONCLUSION

The research shows that construction domestic 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% of 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 structural mechanism.

Apart from that, it is shown that timber-foamed concrete can create the proper density as a floating mechanism in architecture. Samples display results where the density reading is below 1000 kg/m³, despite the compressive strength reading. However, the result for impact after corrosion can't be taken for more extended time for this research paper due to time constraints and a more extended testing period. Further analysis of the timber-foamed concrete and its properties after submerging in the seawater shall be done with better probes and accelerated methods to reduce the timeline of the experiment on the impact of concrete.

In a nutshell, the research paper shows the 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 materiality towards a better and greener material, thus helping the future generations in build and construction environment.

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Tarikh : 20 Januari 2023

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