POTENTIAL APPLICATION OF BIOCOMPOSITE FROM SEAWEED AS A GREEN CONSTRUCTION MATERIAL

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UNIVERSITI TEKNOLOGI PETRONAS

SEPTEMBER 2016

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By

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17376

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil and Environmental Engineering)

SEPTEMBER 2016

Universiti Teknologi PETRONAS,

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CERTIFICATION OF APPROVAL

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BACHELOR OF ENGINEERING (Hons)
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Approved by,

_____

(Dr. Lavania Baloo)

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BANDAR SERI ISKANDAR, PERAK
SEPTEMBER 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMAD AZIM FITRI BIN ABDUL MUIS

ABSTRACT

This research aims to identify the compounds of the materials of the seaweed by finding the most similar properties with cement (cementitious property). Also, this research aims to determine the strength of the strength of mortar, based on range of percentage replacement levels in the mortar (0.1%, 0.5%, 1.0%, and 2.5%) when mixed with seaweed, which *Gracilaria Changii* species was used. In achieving a high strength concrete, a large amount of cement is used whilst a small number of seaweed added in the concrete can enhance the concrete to achieve a higher strength. The seaweed sample was taken abundantly from Pulau Sayak, Kota Kuala Muda, Kedah, which is one of the most prolific area to find this seaweed. The sample was washed until a neutral pH value was achieved then oven dried at 100^{o}C for 24 hours. A part of the oven dried sample was used in mixing in the mortar, while the unused samples were treated with acid and burnt at different temperatures (600^{o}C, 700^{o}C and 800^{o}C). The result from burning will produce a seaweed silica ash, where later were taken for characterization to determine the highest similarity to a cementitious material. From the characterization, the most similar cementitious material to Ordinary Portland Cement (OPC) was used in mixing in mortar with optimum temperature of 600^{o}C. A control mortar mix was used to compare the difference between the oven dried and the treated seaweed sample. 4 mix designs of varying percentage of cement replacement level in the mortar (0.1%, 0.5%, 1.0% and 2.5%) were casted. 10 mortar cubes were casted and later were tested for the compression strength for 3 days, 7 days, 14 days and 28 days. Mortar strength with 0.5% treated seaweed content shows the highest strength of 40.97 MPa at 28 days, while 0.1% treated seaweed content shows mortar strength at 36.61 MPa followed by 0.1% oven dried seaweed content of 34.10 MPa. These 3 mix designs show a greater value than the control mix design which is 28.07 MPa. Thus, using seaweed as a cement replacement material has shown a significant value in compression strength compared to conventional mortar. Therefore, green material is suitable to be used as cement replacement material for a sustainable development.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to The Almighty for granting and giving me this opportunity in my life, and in such great health for me to able pursue my studies until this level. With His Blessings, I have experience a memorable journey that I would cherish for a lifetime.

Also, I would like to thank my supervisor, Dr. Lavania Baloo, for her great support throughout my Final Year Project (FYP). She has given me a chance to pursue my studies by giving me to do the research project under her supervision. She has inspired me a lot of things, as well as teaching me a new field which I did not lean beforehand. There is no way for me to repay the kindness she has provided. As well as for my co-supervisor, Prof. Fadhil Nuruddin, for his vast knowledge he has given to me, advices and feedbacks from his perspectives. An appreciation to my FYP coordinators, for their help to run this research project smoothly and within the time period, as well as guiding me through all the submissions.

Not to forget, the laboratory technicians and graduate assistants for their help in ensuring that I am able to conduct necessary experiments safety and correctly.

Lastly, I could not have done all this without the support from my family and friends. They have supporting me throughout this project and help me with my ups and downs until my research is completed.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

From manufacturing cement, roughly 8 to 10 percent of the world's total CO_2 emissions come from this industry. The global warming gas is released when limestone and clays are crushed and heated to high temperatures. Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or it has high performance and life cycle sustainability [2].

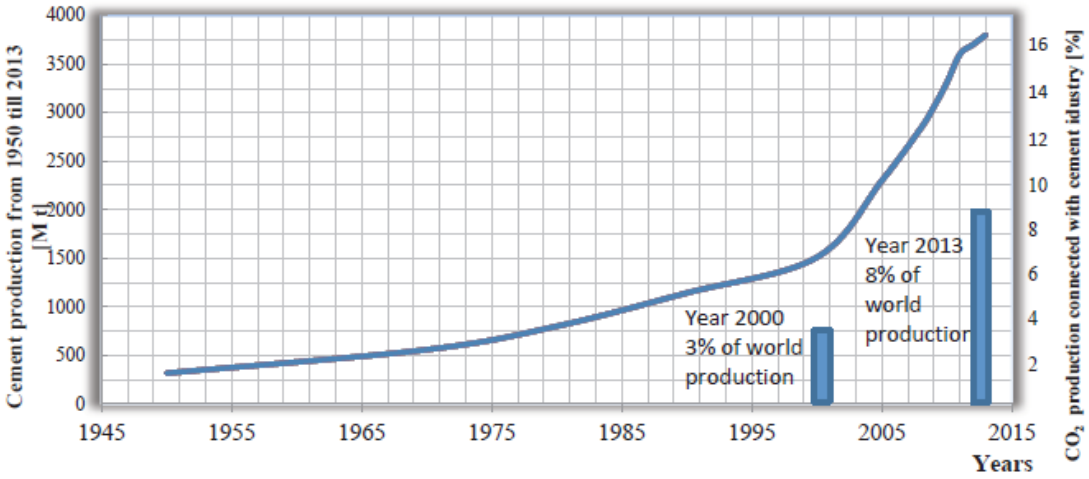

Figure 1: The increment of the cement production and CO_2 produced prior to the cement industry from 1950 till 2013[2].

Other CO_2 emission comes from burning and usage of fossil fuels, transportation, electricity and other sources.

Various efforts have been carried out by researchers to find alternative ways to reduce the CO_2 emission. For instance, alternative concrete making materials have been trialed in reinforced concrete structures such as recycled concrete aggregate and agriculture waste materials, among others, to reduce the dependency on conventional concrete constituent materials, which are fast depleting. One of the primary environmental concerns from concrete-based building materials is the high amount of carbon dioxide emission, which arises during the manufacturing of cement [12].

One of the alternatives is the use of seaweed as a possible cement replacement material in building application. The idea is that when applying the seaweed to the concrete mix, it has the potential to enhance the strength of the concrete. *Eucheuma Cottonii* is polysaccharide that contains kappa carrageenan. It has advantage as emulsifier, suspensor, condenser, and stabilizer. *Gracilaria Sp*. is also polysaccharide which contains agarose and agaropectin that make strong gel. It is also noted that *Cottonii* (gel) and *Gracilaria Sp*. (powder) have rheological properties as gelling and thickening agents that which can perform as epoxy resin in polymer modified mortar. According to the advantage of seaweed, this natural polymer modified mortar is expected to perform excellent bonding mechanism, strength, and durability as the key factor to achieve sustainability [22].

Natural fibers are subdivided based on their origins, coming from plants, animals or minerals. All plant fibers are composed of cellulose while animal fibers consist of proteins (hair, silk, and wool). Plant fibers include bast (or stem or soft sclerenchyma) fibers, leaf or hard fibers, seed, fruit, wood, cereal straw, and other grass fibers. The use of such materials in composites has increased due to their relative cheapness, their ability to recycle and for the fact that they can compete well in terms of strength per weight of material. Natural fibers can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. The cellulose fibrils are aligned along the length of the fibre, which render maximum tensile and flexural strengths, in addition to providing rigidity [25].

The history of fire-reinforced plastics began in 1908 with cellulose fire in phenolics, later extending to urea and melamine and reaching commodity status with glass fibre-reinforced plastics. Natural fibres are subdivided based on their

origins, coming from plants, animals or minerals. All plant fibres are composed of cellulose, while animal fibres consist of protein (hair, silk and wool). Plant fibres include bast (or stem or soft sclerenchyma) fibres, leaf or hard fibres, seed, fruit, wood, cereal straw and other grass fibres [31].

Biocomposite is a composite material formed by a matrix and a reinforcement natural fibres. These kinds of materials often mimic the structure of the living materials involved in the process keeping the strengthening properties, but providing biocompability. The matrix is formed by polymers which can be a renewable or non-renewable resources; it is important to protect the fibres from degradation and mechanical damage, to hold the fibres together as well as transferring loads on it [5,6].

Table 1: Types and examples of biocomposites.

	Biocomposites						
	Non-wood natural fibres					Wood fibres	
	Straw fibres	Bast	Leaf	Seed/Fruit	Grass fibres		Recycled
Example	Rice, wheat, corn straws.	Kenaf, flax, jute, hemp.	Henequen, sisal, pineapple leaf fibre.	Cotton, coir, coconut.	Bamboo, elephant grass.	Soft and hard woods.	Newspaper, magazine fibres.

The fibres most widely used in the industry are Flax, Jute, Hemp, Kenaf, Sisal and Coir. The wood fibres could be recycled or non-recycled. Thus, many polymers such as polyethylene, polypropylene, and polyvinyl chloride (PVC) are being used in wood composites industry.

The interaction between the biocomposites can strengthen the concrete as well as gives positive results in chemical and mechanical properties. The composites' shape, surface appearance, environmental tolerance and overall durability are dominated by the matrix while the fibrous reinforcement carries most of the structural loads, thus providing macroscopic stiffness and strength [3,8].

1.2 PROBLEM STATEMENT

A huge amount of cement is used to achieve higher concrete strength, whilst a small number of seaweed added in the concrete mix can enhance the concrete to achieve a higher strength.

Conventional concrete cannot withstand at high temperature. Not only that, application of seaweed has many advantages to offer; good heat insulator, non-toxic to the surrounding, fireproof, low-energetic, and biodegradable with life expectancy of 150 years. But the main reason that the use of seaweed should give, is providing a new alternative in the concrete industry so that the cement production can be reduced gradually [16].

In this era where the environment is threatened by various sources, and one of them is CO_2 gas emission, and the main source of this gas is the production of cement. By using seaweed as a cement replacement material in concrete mix, we can reduce the use of cement, and therefore we can reduce the CO_2 gas emission. The best cement replacement material result will have the highest strength based on the tests and correlate with the carbon footprint.

1.3 OBJECTIVES

The following objectives are revised to fulfill the requirements;

i. To identify the composition of materials in the seaweed, which later can be used in either as a cement replacement material or a filler for biocomposite.
ii. To determine the strength of concrete based on a range of seaweed percentage replacement in the concrete (0.1%, 0.5%, 1.0%, 2.5%).

1.4 SCOPE OF STUDY

In this study, the seaweed is used in the concrete mix to act as a cement replacement material. The seaweed may be reinforced to become biocomposites which may give a better result. The cement replacement materials was included in the mix design and later be added in the batching process. Several cement

replacement materials will be carried out as well to compare the results based on compressive strength test and tensile strength test of the concrete.

1.5 SIGNIFICANCE OF THE PROJECT

It is important for the researchers to identify the benefits of their study to the society and the environment. The benefits are as follows:

i. To use naturally available resources such as seaweed as a cement replacement material in building application.
ii. To explore new alternatives of cement replacement materials as the concrete demand is highly increasing.
iii. To enhance the strength of the concrete by varying the seaweed content in the concrete, and;
iv. To reduce the CO_2 emission and control the greenhouse gases.

CHAPTER 2

LITERATURE REVIEW

2.1 EFFECTS OF CEMENT PRODUCTION

It has been noticed, that concrete is second after sweat water product used by people on our planet. This is good and unfortunately bad information. Good because of fact, that thanks to concrete we can build solid and sustainable structures making our life easier and better. Bad because making a concrete relates to huge energy cost and even bigger emission of greenhouse gasses [2].

Suhendro (2014) said that the conservation and environmental protection has become a major world issue in the global context. Since the World Earth Summit 1997 in Kyoto, Japan, which initiated the need to reduce CO_2 emissions on a large scale (targeted before 2010 emissions reduced by about 21%) to avoid catastrophic global world, so many huge industrial countries around the world have agreed to formulate regulations that dreams related to the mission of the protection and preservation of the environment can become reality [10,11]. About 8 ~ 10% of total world CO_2 emissions, which are believed to be the main drivers of global climate change did not come from polluting vehicles on the highway or a forest fire, but comes from the cement manufacturing process in cement factories [1]. Global warming gas is released when the raw material of cement, limestone and clay is crushed and heated in a furnace at high temperature (± 15000^{o}C). Each year, approximately 1.89 billion tons of cement (which is a major component of concrete) have been produced worldwide [12].

Long & Xie (2015) stated that concrete is one of the most widely used building materials with a global consumption rate approaching 25 gigatons (Gt) per year [7]. CO_2 (from industries and the use of fossil fuels) emitted from concrete production and

transportation is estimated to be approximately 10% of the total man-made CO_2 in the atmosphere; consequently, its environmental burden is significant in terms of environmental emissions, energy consumption and resource use [17].

2.2 CEMENT REPLACEMENT MATERIALS (CRM)

Because of the significant benefit of carbon footprint reduction with the use of cement-less geopolymer concrete, researches had shifted their focus towards the study of the behavior of geopolymer concrete on micro- and macro-scales. The most important application of concrete in building construction is nonetheless reinforced concrete structural members [9].

Long, Gao & Xie (2015) quoted that several efforts have been done to achieve the sustainable concrete. Those efforts make the concrete technology innovation 'green', less energy, and less carbon emission. There is a concept to make concrete becoming green construction material, "Triangle of Virtuous Concrete Principle" which is stated by Susilorini. The "Triangle of Virtuous Concrete Principle" is connecting the 3 aspects of sustainable development, infrastructure development, and carbon footprint reduction to be unity [13]. Susilorini et al. (2014) justify that connecting the three aspects in the "Triangle of Virtuous Concrete Principle", concrete will truly become virtuous and green construction material. It is known that concrete technology innovations have been implemented in construction industry. However, those innovations are still limited to meet criteria of green construction material. Therefore, we need more breakthroughs of concrete technology to fulfil the worldwide needs of green construction material [13].

2.3 POSSIBLE USE OF SEAWEED AS CEMENTATIOUS MATERIAL

Bertron (2014) said that the modelling of interactions between cementitious materials and the microorganism-bearing environment is also in its early stages. It is, however, a high-priority issue to complete the understanding of these interactions on the one hand and to predict the material/product/structure service life duration on the other [20-21]. The double challenge is to model (i) the activity of microorganisms and

biofilm at the surface of a highly reactive material such as concrete and (ii) the impact of specific metabolites (H_2SO_4, citric acid, etc.) that produce expanding secondary products by reaction with the cementitious matrix, which in turn creates cracking within the matrix and modifies its transfer and mechanical properties [19].

2.4 SEAWEED AS A FILLER IN BIOCOMPOSITE

Seaweed (SW) can offer high productivity of biomass while also allowing productive land to be put to other uses. SW is a pure natural material that offers numerous advantages, such as excellent heat insulation and heat capacity characteristics as well as full biodegradability and strong carbon dioxide fixation. It offers energy-absorbing properties due to fibrils, leading to outstanding insulation and sound-absorption characteristics. In addition, it works as a brilliant flame retardant [4]. Despite its many advantages, SW derived from chemical reactions for bio-energy production is associated with disposal problems. Therefore, SW was studied as reinforcing material for biocomposites in an effect to utilize it as a beneficial material [4,5,8].

Per the advantage of seaweed, this natural polymer modified mortar is expected to perform excellent bonding mechanism, strength, and durability as the key factor to achieve sustainability [9].

Widera (2014) justified that due to the continuous emission of CO_2 to the atmosphere, the amount of seaweed in the seas and oceans is increasing. That should put our attention on this plant as a potential building material and a source of energy, especially today, when many countries are threatened with deforestation and we are looking for cheap materials alternative. The important advantages of seaweed should be widely recognized: it provides good insulation, great acoustics, humidity control, visual comfort and the reduction of CO_2 emission. It is also non-toxic, fireproof, low-energetic, biodegradable with a life expectancy of more than 150 years.

As any other organic materials, polymers and natural fibre are very sensitive to fire/flame and hence improvement of fire retardancy of the composite materials has become more and more important to comply with safety requirements of the natural fibre/composite products [14]. Seaweed is a pure natural material that offers numerous

advantages like high heat insulation, heat capacity and, therefore, is an effective heat protection during summer. It has a good ability of humidity regulation, good processing properties, and excellent elasticity characteristics. Other qualities are its full recyclability and strong carbon dioxide fixation. It offers energy absorbing material properties because of fibrils that lead to outstanding insulation and sound-absorption characteristics. In addition, it works as a brilliant flame retardant [16].

2.5 NATURAL FIBRES TO REINFORCE THE BIOCOMPOSITE

Natural fibres have been increasingly used as reinforcing materials in biocomposites. Biocomposites utilize natural fibres as reinforcement and polymers as matrix for composites. Advantages of natural fibres over traditional reinforcing materials such as glass and carbon fibres are low cost, low density, renewable, biodegradability, etc. For this reason, biocomposites have several advantages such as eco-friendly, lightweight, energy saving and carbon dioxide reduction characteristics [6].

The plants, which produce natural fibres, are classified as primary and secondary depending on their utilization. Primary plants are those grown for their fibre content while secondary plants are plants in which the fibres are produced as a by-product. Jute, hemp, kenaf, and sisal are examples of primary plants. Pineapple, oil palm and coir are examples of secondary plants. Table 2 shows the main fibres used commercially in composites, which are now produced throughout the world [3].

Table 2: Commercialized major fibre source.

Fibre source	World Production (10^3 tonne)
Bamboo	30000
Jute	2300
Kenaf	970
Flax	830
Sisal	378
Hemp	214
Coir	100
Grass	700

There have been many studies of SW reinforcement in biocomposites such as red algae fiber/PBS, SW/PP, and SW residues/HDPE composites. The results demonstrate that SW is an excellent reinforcement for biocomposites and that SW-reinforced biocomposites can be used in various applications in the automotive industry, as interior trim for instance, and in the construction industry [13].

They exhibit several advantages, which explains the growing interest of composite manufacturers (mainly in automobile and building industries), wishing to replace the more commonly used glass fibres. Asia, thanks to the large variety of climates it offers, gathers several types of vegetable fibre harvests; bamboo, abaca, sisal, kenaf, ramie, flax, hemp, coir, jute, cotton, isora, vakka, okra, and china reed are available locally in this part of the world. Furthermore, vegetable fibres are known to be CO2 neutral, since their compositing or combustion does not release into the atmosphere their excess in carbon dioxide (captured through photosynthesis to produce the sugars of their skeleton). Their production and extraction generally require low amount of energy, per the species considered, compared to the fabrication of synthetic fibres which consumes high levels of energy (mainly through heating) [31].

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW METHODOLOGY

The purpose of this chapter is to explain the method and technique used in this study to achieve the main objectives. The research is divided into three (3) stages:

i. Phase 1: Sample collection; seaweeds and preparation for pretreatment and mortar mixing.
ii. Phase 2: Pre-treatment and preparation of seaweed.
iii. Phase 3: Fabrication of seaweed and testing of samples.

Phase 1, is the seaweed sample collection, preparation for pre-treatment of the seaweed.

Phase 2, is the pre-treatment of the seaweed to mix with the mortar, and characterization test to find the suitable mix.

Finally, for Phase 3, several tests were conducted to find the compressive strength of the mortar, and characterization tests to support the findings.

Four sets of mix design (0.1%, 0.5%, 1.0%, 2.5%) were casted using the seaweed in the mortar. Also, the conventional (control) mix design is used to make the comparison between the strength. Each set had 10 cubes; where one cube was tested on 3-days after the concrete is cured, 3 cubes on 7-days, 14-days and 28-days respectively after curing.

All results are gathered for final analysis before conclude the experiment. Figure 2 below shows the overview flowchart of the methodology of this project.

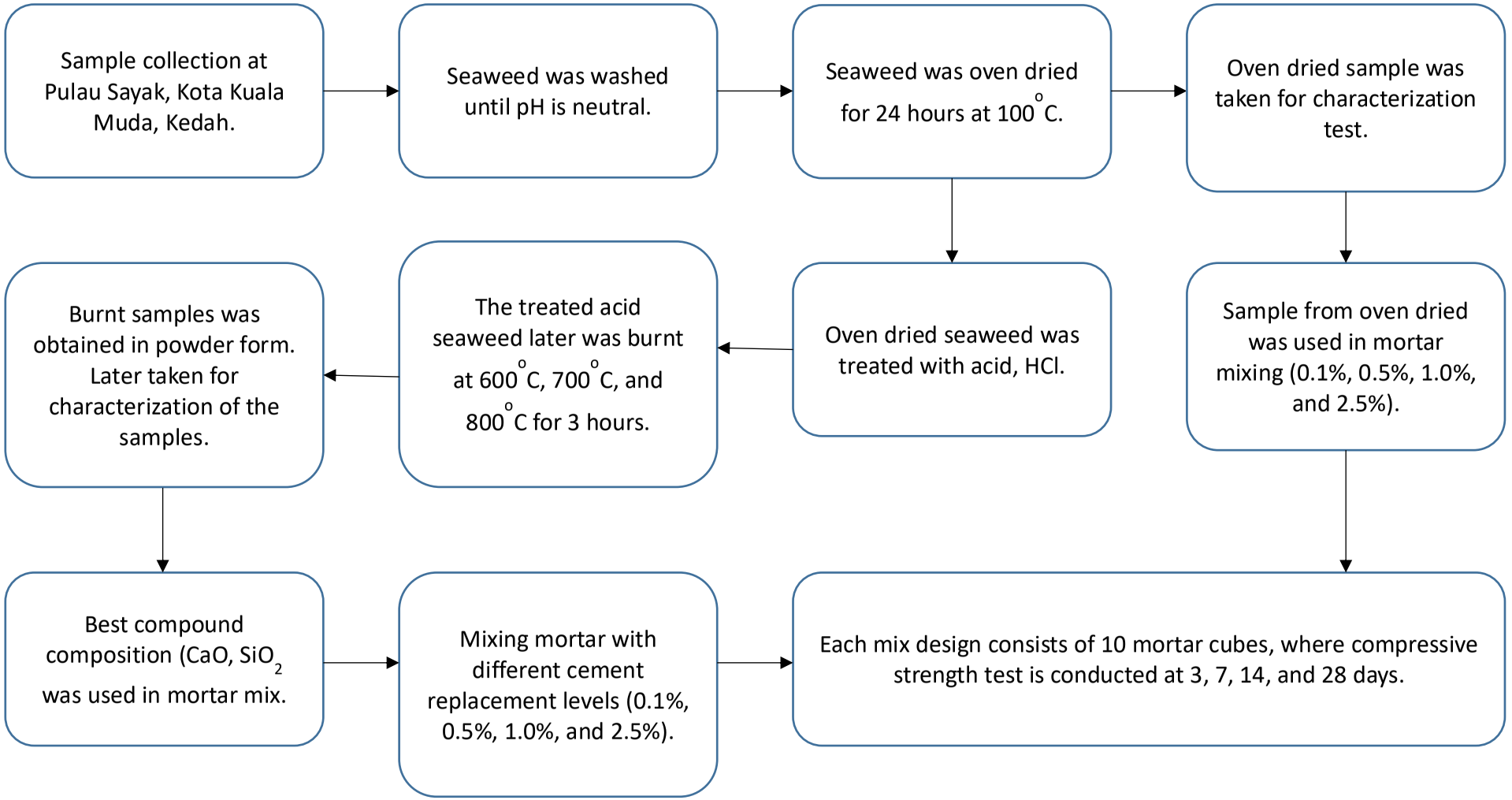

Figure 2: Overview of the methodology.

Figure 2 above shows the overview methodology of the project. First, the seaweed was collected from the fishery department in Pulau Sayak, Kota Kuala Muda, Kedah. It was taken back to the lab to wash any impurities until the pH obtained was neutral. After the pH is neutral, it is proceeded to oven dried for 24 hours at 100^{o}C. The weight of the sample before it was oven dried and the weight after it has been dried were recorded to calculate the water moisture content.

After it has been oven dried, the method splits into two; i) the oven dried sample was taken for characterization test and later used directly in mortar mixing. ii) the oven dried sample was proceeded to acid treatment, where hydrochloric acid (HCl) was used in this project. 0.1 M of HCl was used, and 5.0L of HCl is mixed with 100g of the oven dried sample. This is to make sure that the oven dried seaweed sample surfaces are in contact with the acid, to break down the surrounding layer or lignin layer that surrounds the seaweed. The acid treatment is carried out for 24 hours at room temperature. After the acid treatment has been completed, it can proceed to burning in the furnace. The treated seaweed was burnt at different temperatures of 600^{o}C, 700^{o}C, and 800^{o}C for 3 hours. The burnt sample later was obtained in powder form, or silica ash. Then the burnt samples were taken for characterization tests, where the highest similarity to cementitious material was selected to be mixed in the mortar.

Samples from both methods were later mixed in mortar with different percentage of cement replacement level (0.1%, 0.5%, 1.0%, and 2.5%). Each mix designs consists of 10 ten cubes where compressive strength test is conducted on 3-days, 7-days, 14-days, and 28-days respectively.

3.2 ACID DILUTION

The acid used is Hydrochloric Acid (HCl) (Fuming 37%), with molecular weight of 36.45 is an analytical reagent.

$M = (fume\%/100) \times (p/mw) \times (1000mL/1L)$

$= (37/100) \times (1.19/36.45) \times (1000mL/1L)$

$= 12.08\ M$

$M_1V_1 = M_2V_2$

$12.08V_1 = 0.1(1000)$

$V_1 = \underline{8.28\ mL\ of\ HCl}.$

For dilution, the 8.28 mL of HCl is diluted in 1000 mL volumetric flask, and the pH is determined before mixing it with the seaweed sample. Also, 5.0L of diluted acid is used to mix with only 100g of seaweed sample. This is to make sure that the surface of the seaweed sample is in contact with the acid, to break down the lignin layer that surrounds the seaweed sample.

3.3 X-RAY DIFFRACTION (XRD) EXPERIMENT

X-Ray Diffraction (XRD) is a laboratory-based technique commonly used for identification of crystalline materials and analysis of unit cell dimensions. One of two primary types of XRD analysis (X-ray powder diffraction and single-crystal XRD) is commonly applied to samples to obtain specific information about the crystalline material under investigation. X-ray powder diffraction is widely used in geology, environmental science, material science, and engineering to rapidly identify unknown crystalline substances. A pure, finely ground, and homogenized sample is required for determination of the bulk composition. Additional uses include detailed characterization of crystalline samples, determination of unit cell dimensions, and quantitative determination of modal amounts of minerals in a sample. X-ray powder diffraction can also be applied to the identification of fine-grained minerals.

Samples from oven dried, 600^{o}C, 700^{o}C and 800^{o}C were taken to conduct the XRD experiment. From the XRD test conducted, the results shown the compounds of the samples, later were compared to the cement compounds. The highest similarity to the cementitious material (CaO, SiO_2, Al_2O_3, Fe_2O_3, and S) was then selected to proceed to the next test.

3.4 MORTAR MIXING AND MIX DESIGN

From the XRD test, the selected sample was later proceeded to the mortar mixing. The sample replaced the cement in the mortar based of a percentage of replacement levels (0.1%, 0.5%, 1.0%, and 2.5%). Therefore, for the oven dried sample as well as the treated selected sample have 4 different mix designs each.

There are ten mix designs varying the seaweed content by replacing cement in the mortar.

Table 3: Classification of mix design.

Mortar Sample	Description
A	Conventional (control)
B	Oven dry (0.1%)
C	Oven dry (0.5%)
D	Oven dry (1.0%)
E	Oven dry (2.5%)
F	Burning (0.1%)
G	Burning (0.5%)
H	Burning (1.0%)
J	Burning (2.5%)

Volume of mold (mm^3) = 50 x 50 x 50

= 125000

= 0.000125 m^3

Water cement ratio = 0.45

Cement sand ratio = 1:3

Density:

Cement = 1500 kg/m^3

Sand = 1600 kg/m^3

Water = 1000 kg/m^3

Volume of cement = $\frac{0.000125 \times 1}{4}$

= 0.00003125 m^3

Volume of sand = $\frac{0.000125 \times 3}{4}$

= 0.00009375 m^3

The volume of cement and sand were multiply with the density of cement and sand respectively to obtain for one cube.

For one cube, the calculation is done and summarized in the table below.

Table 4: Calculation for one cube.

Cement	Sand	Water
47 g	150 g	21.15 g

And for the calculation for 10 cubes is summarized in table below.

Table 5: Calculation for ten (10) cube.

Cement	Sand	Water
470 g	1500 g	211.5 g

Table below shows the calculation for each mix design. The design is added 25% so that when mixing, it has an extra for compaction.

Table 6: Calculation mix design.

	Seaweed (g)	Cement (g)	Sand (g)	Water (g)
Conventional	0	587.5	1875	262.5
0.1% seaweed	0.6	586.9	1875	262.5
0.5% seaweed	2.9	584.6	1875	262.5
1.0% seaweed	5.9	581.3	1875	262.5
2.5% seaweed	14.7	572.5	1875	262.5

Before mixing the mortar, a few preparations are needed before it can begin with. Firstly, the mold was prepared by tightening the screws to prevent leakage, and oil was wiped across the mold so that the mortar does not stick to the mold when unscrewing the mold. Then the samples were prepared and measured; cement, sand, seaweed, and water.

The mixing mortar starts with by placing the sand inside the mixing bowl. Then, it is proceeded by adding the measured cement, followed by the seaweed sample. The mixer started to mix the mixture for 30 seconds, then the measured water is added into the mxi. This is to blend the mixture together and the water acts as a medium for the sand and cement and seaweed to mix together. It is later continued to mix for another 30 seconds before the mixer was stopped. The mixed mortar was placed into the mold that was prepared earlier.

After the mortar has been placed into the mold, it was taken for compaction. This is to fill the spaces and gaps in the mold. After it has been compacted, it was left to dry at room temperature before unscrewing the mold the following day. When the mold has been opened, the mortar was placed inside a curing tank until a testing date approaches (3-days, 7-days, 14-days, and 28-days after mortar was casted).

3.5 FIELD EMISSION-SCANNING ELECTRON MICROSCOPE (FESEM)

The FESEM uses a beam of electron shot towards a sample to obtain information about it, including what the surface looks like and the chemical make up the sample. The electrons interact with the surface molecules to relay information back to the user.

For analysis done for this FESEM test is Energy-dispersive X-ray spectroscopy (EDX). It is an analytical technique used for elemental analysis or chemical characterization of a sample.

The samples taken for FESEM test are the (i) oven dried sample, (ii) selected burnt sample that shows the highest similarity to cementitious property, (iii) oven dried crushed mortar sample, (iv) selected burnt mortar sample, and (v) crushed conventional mortar sample. The magnification for EDX considered was 1000x magnification.

3.6 BRUNAUER, EMMETT AND TELLER (BET)

BET (Brunauer, Emmett and Teller) the specific surface area of a sample is measured – including the pore size distribution. This information is used to predict the dissolution rate, as this rate is proportional to the specific surface area. Thus, the surface area can be used to predict bioavailability. Further it is useful in evaluation of product performance and manufacturing consistency.

The specific surface area of a powder is determined by physical adsorption of a gas on the surface of the solid and by calculating the amount of adsorbate gas corresponding to a monomolecular layer on the surface. Physical adsorption results from relatively weak forces (van der Waals forces) between the adsorbate gas molecules and the adsorbent surface area of the test powder. The determination is usually carried out at the temperature of liquid nitrogen. The amount of gas adsorbed can be measured by a volumetric or continuous flow procedure.

The cement, sand, and the selected seaweed sample were taken for BET test, because it is used to determine the surface area of the sample and compared it to cement and sand.

3.7 PROJECT MILESTONES AND TIMELINE

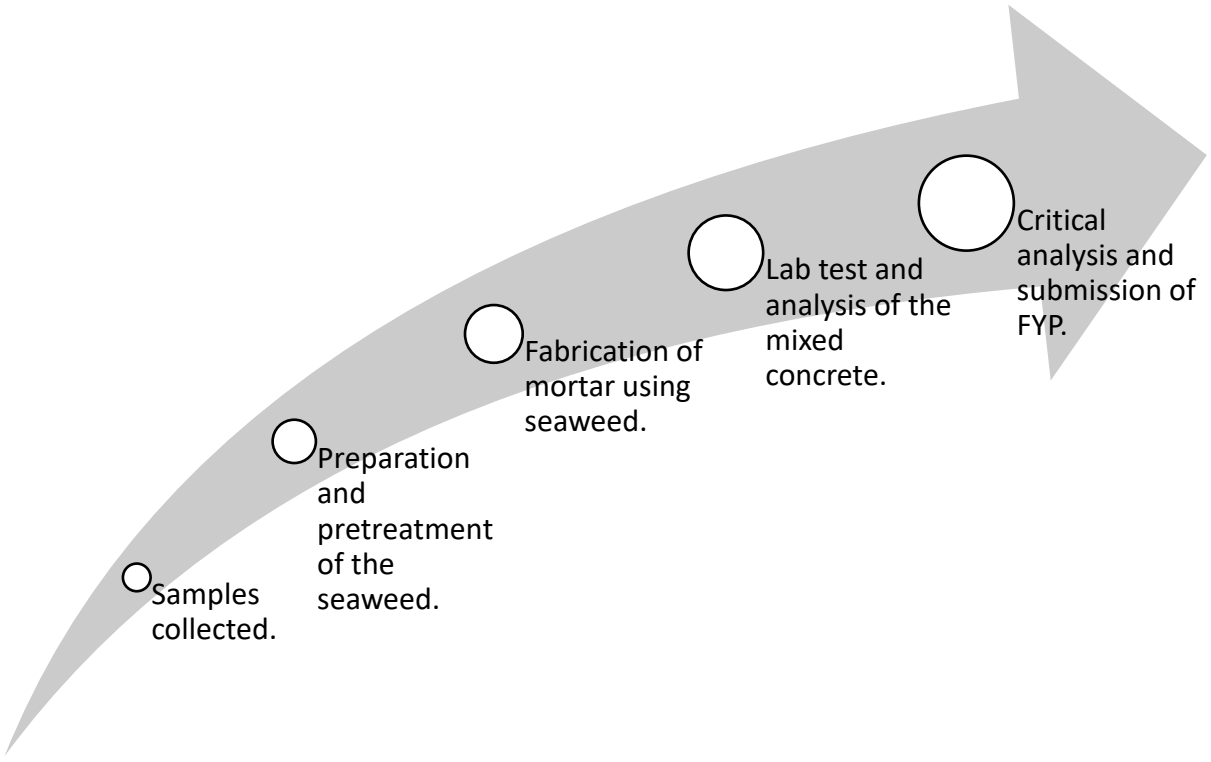

Figure 3: Project milestone.

Table 7: Project timeline.

	Tasks	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Semester 1	Topic Selection														
	Literature Review														
	Extended Proposal Defense Presentation														
	Field Work: i. Observation on land reclamation. ii. Data gathering and sampling.														
	Lab Work: i. Pre-treatment of seaweed ii. Mix Design calculation.														
	Submission of Interim Draft Report														
	Tasks	**Week**													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Literature Review														
Semester 2	Lab Work: i. Seaweed characterization ii. Compressive strength test														
	Result Analysis														
	Submission of Dissertation (Hardbound)														

CHAPTER 4
RESULTS AND DISCUSSION

4.1 MOISTURE CONTENT AND pH

The seaweed is divided into several batches to wash and analyze. The seaweed was oven dried at 100^{o}C for 24 hours.

Table 8: Moisture content and pH

Batch	Wet Sample (g)	Dry Sample (g)	pH
1	415.3	43.28	6.51
2	446.5	41.66	7.11
3	459.1	37.46	6.92
4	526.1	51.09	6.88
5	488.6	37.25	7.36
6	556.7	50.06	7.06
7	492.8	42.39	6.78
8	502.6	42.62	6.91
9	748.3	115.48	7.20
10	1226.2	165.21	7.01
11	842.6	108.11	6.85
12	611.5	50.09	7.14
13	962.3	112.69	7.09
14	1648.2	161.79	7.18
15	472.3	58.99	7.05
Average	693.27	74.54	7.00

$$\text{Moisture Content (\%)} = \frac{Wet\ Sample - Dry\ Sample}{Wet\ Sample} \times 100$$

$$= \frac{693.27 - 74.54}{693.27} \times 100$$

$$= \underline{\mathbf{89.25\ \%}}$$

4.2 XRD TEST RESULT

The samples taken for XRD Analysis were 600ºC, 700ºC and 800ºC burnt sample. The samples were analyzed to determine the crystalline surface of each element found in the samples. The crystalline surfaces later will indicate the highest probability of elements in the sample to the data library of the software used. And in this case, the software used were DIFFRAC.EVA v4.1.1 and HighScore Plus v 3.0.4. These software is specially made in determining the crystalline surface as well as identifying the elements of the sample.

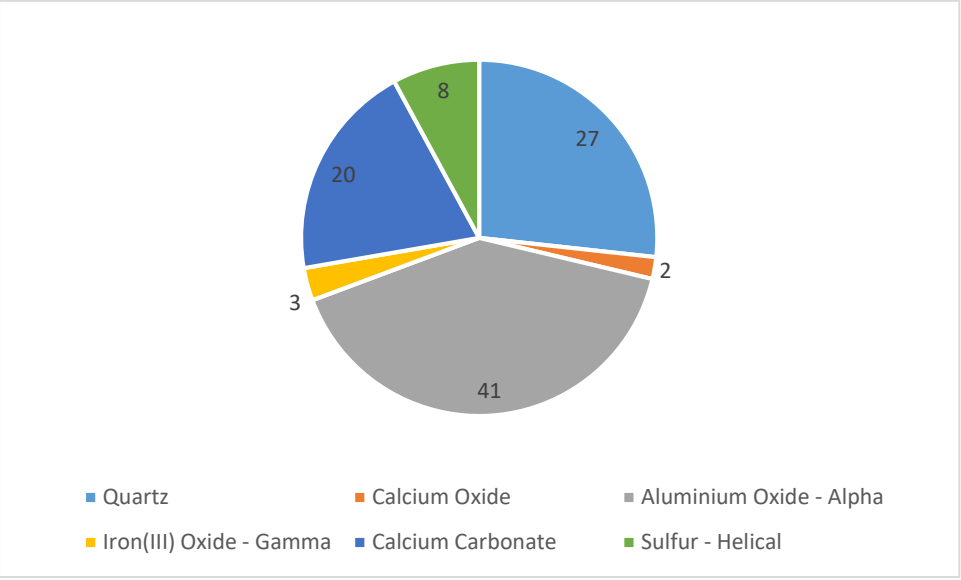

Figure 4: Cementitious elements in 600ºC burnt sample.

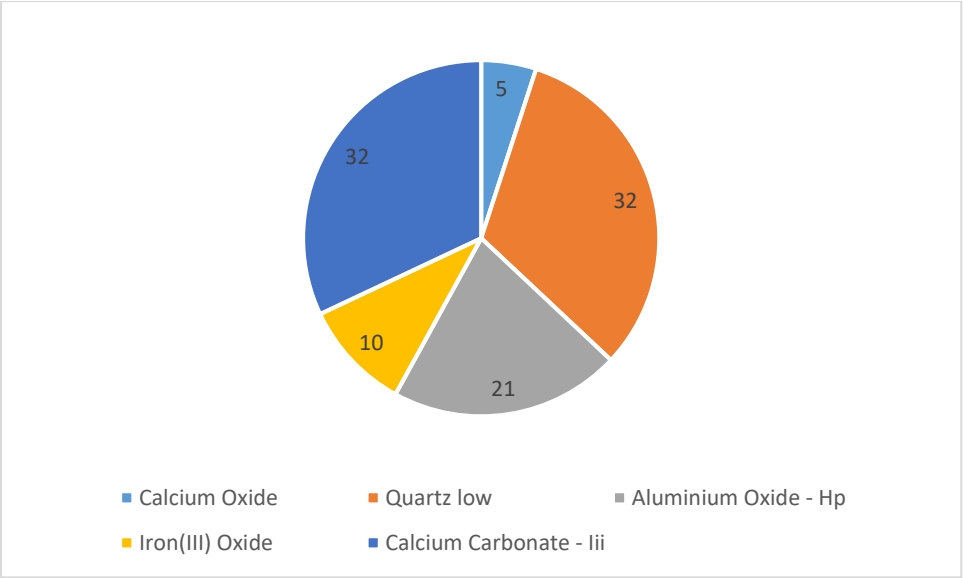

Figure 5: Cementitious elements in 700°C burnt sample.

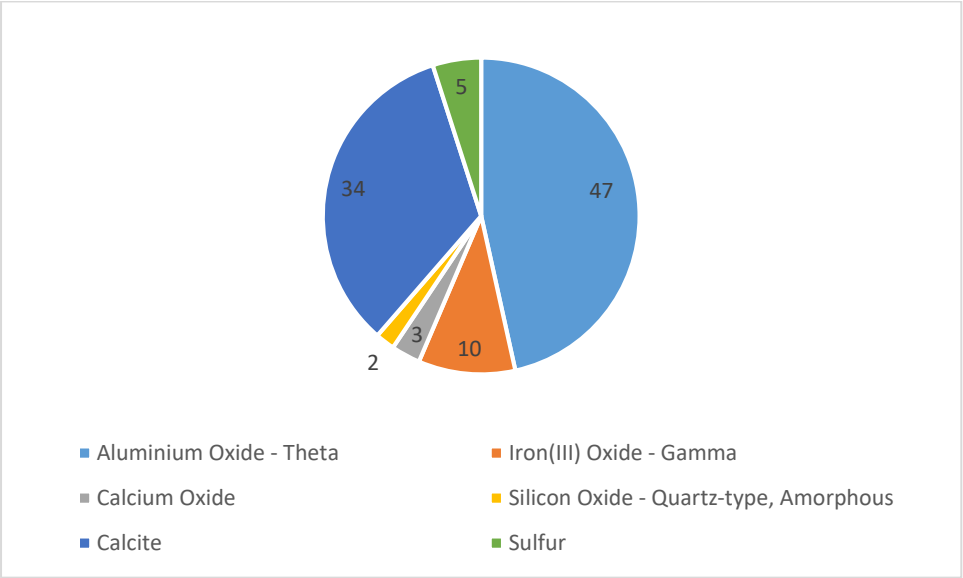

Figure 6: Cementitious elements in 800°C burnt sample.

To summarize the element properties in each sample, the elements is compared to the elements in the cement.

Table 9: Comparison of cementitious properties between cement and the burnt samples.

Properties	Ordinary Portland Cement (%)	600°C burnt sample (%)	700°C burnt sample (%)	800°C burnt sample (%)
Calcium Oxide, CaO	61 - 67	~20	~5	~3
Silicon Oxide, SiO_2	19 - 23	~26.7	~32	~2
Aluminum Oxide, Al_2O_3	2.5 - 6	~41	~21	~47
Ferric Oxide, Fe_2O_3	0 - 6	~3	~10	~10
Sulfate, S	1.5 - 4.5	~7.9	N/A	~5

From the table above, 600°C burnt sample shows the highest similarity compared to the cement itself. Therefore, the 600°C burnt sample was taken for further experiments by mixing it in the mortar to test for compressive strength. The cement was replaced by the selected 600°C burnt sample in the mortar by several replacement levels (0.1%, 0.5%, 1.0%, and 2.5%). This is to show the compressive strength at different replacement levels.

4.3 COMPRESSIVE STRENGTH RESULTS

The compressive strength test was conducted on the mortar on 3-days, 7-days, 14-days, and 28-days to determine the compressive strength of the mortar. The results below are the summarized average for each day and the full results list is listed in the appendices.

Table 10: Average compressive strength at 3,7,14, and 28 days.

Mix Design	Compressive Strength (kN)			
	3 days	7 days	14 days	28 days
Control Mix, A	22.47	20.63	22.81	28.07
0.1% oven dried, B	11.57	13.70	29.76	34.10
0.5% oven dried, C	10.68	10.53	17.81	11.11
1.0% oven dried, D	13.31	20.50	19.27	17.03
2.5% oven dried, E	9.98	11.91	14.34	19.05
0.1% burnt sample, F	23.02	17.09	28.98	31.99
0.5% burnt sample, G	12.35	20.91	21.63	40.97
1.0% burnt sample, H	12.66	15.39	15.72	19.11
2.5% burnt sample, J	9.26	12.77	14.33	17.39

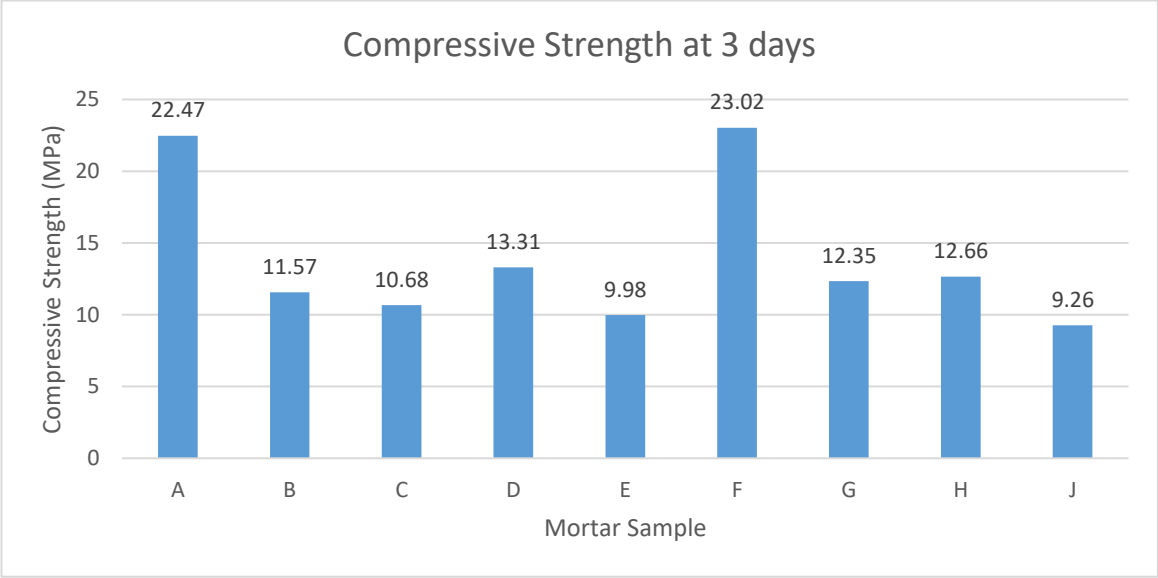

Figure 7: Compressive strength at 3 days.

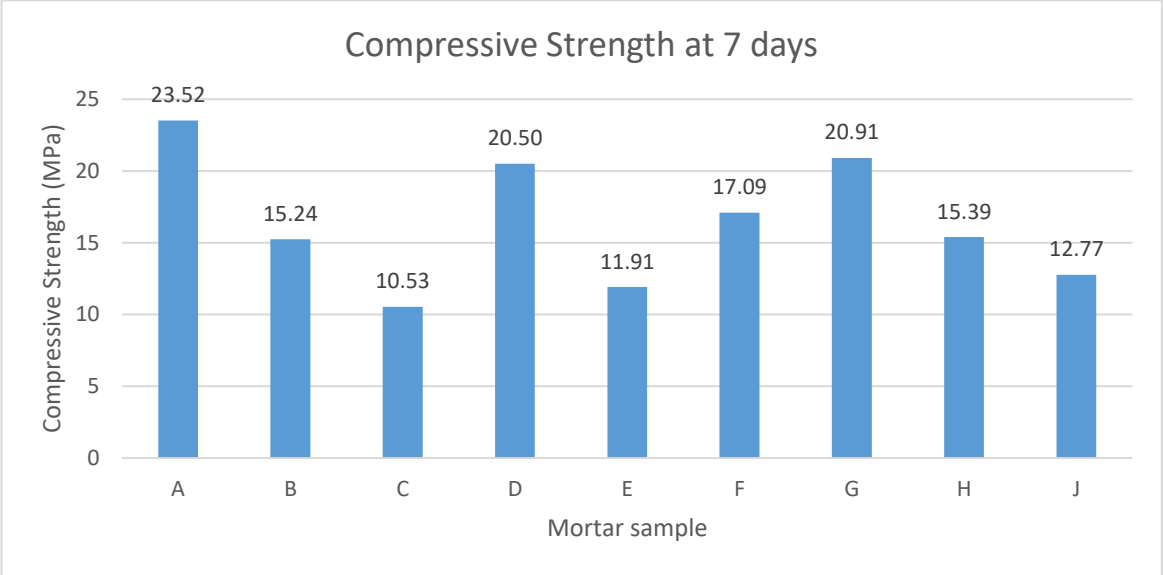

Figure 8: Compressive strength at 7 days.

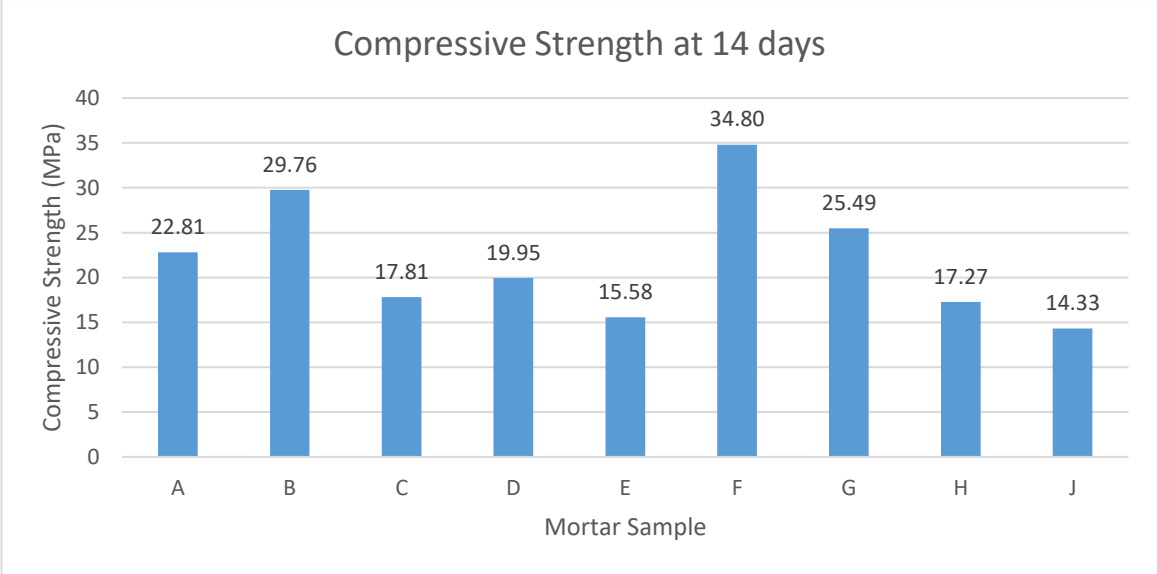

Figure 9: Compressive strength at 14 days.

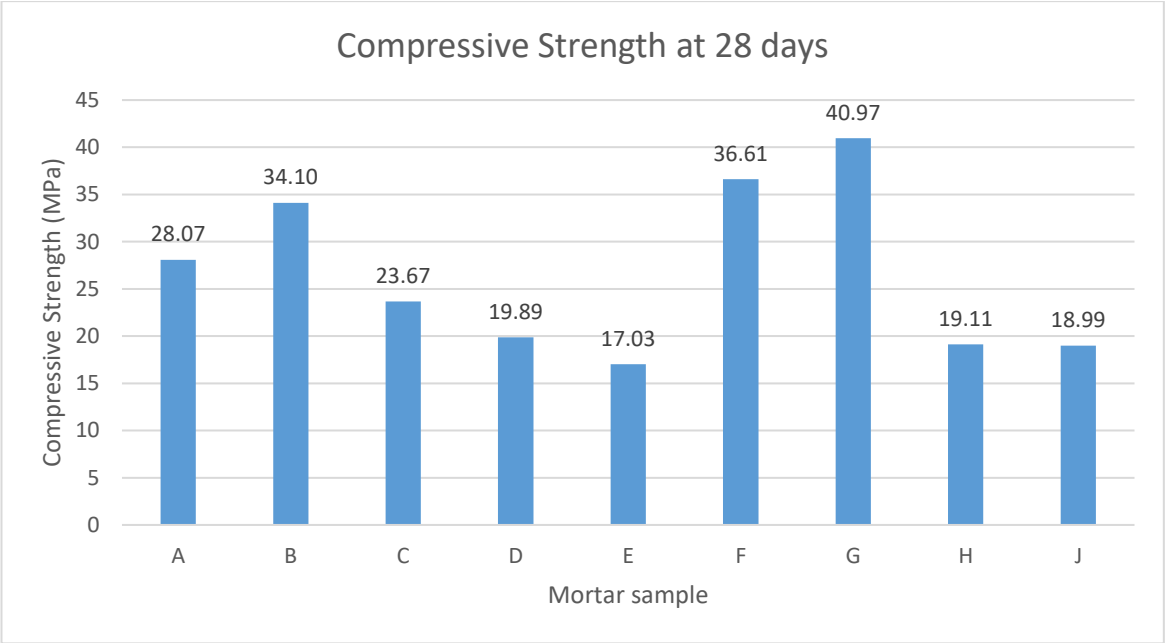

Figure 10: Compressive strength at 28 days.

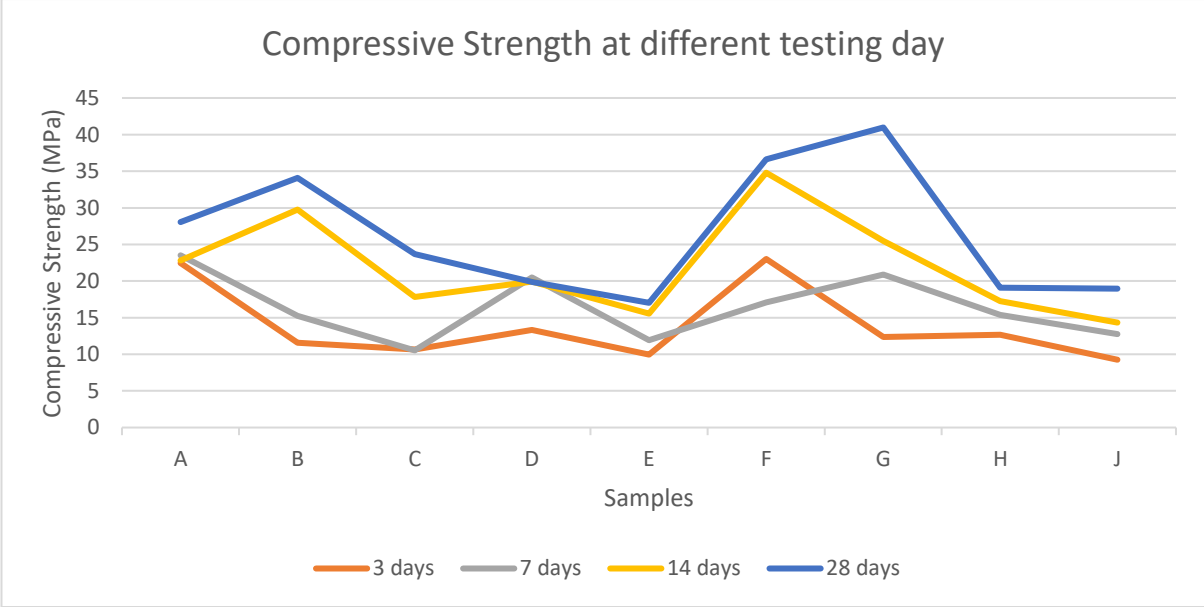

Figure 11: Compressive strength of mortar at different testing days.

From the graphs above, the 0.5% burnt sample shows the highest compressive strength at 40.97 MPa compared to the other mix designs. 0.1% burnt sample (36.61 MPa) and 0.1% oven dried sample (34.10 MPa) also shows a greater compressive strength when compared to the control mix at 28.07 MPa.

From Figure 13, there is a trendline for the oven dried sample and burnt sample. For the oven dried sample, 0.1% oven dried shows the highest, and the compressive strength is gradually decreasing until 2.5% oven dried. It is similar for the burnt sample, from 0.1% burnt sample, the compressive strength goes higher to 0.5% burnt sample, and later it gradually decreases until 2.5% burnt sample. It is observed that the optimum seaweed content in the mortar to achieve a higher compressive strength for the oven dried is 0.1%, and 0.5% for the burnt sample.

4.4 FIELD EMISSION-SCANNING ELECTRON MICROSCOPE (FESEM) RESULT

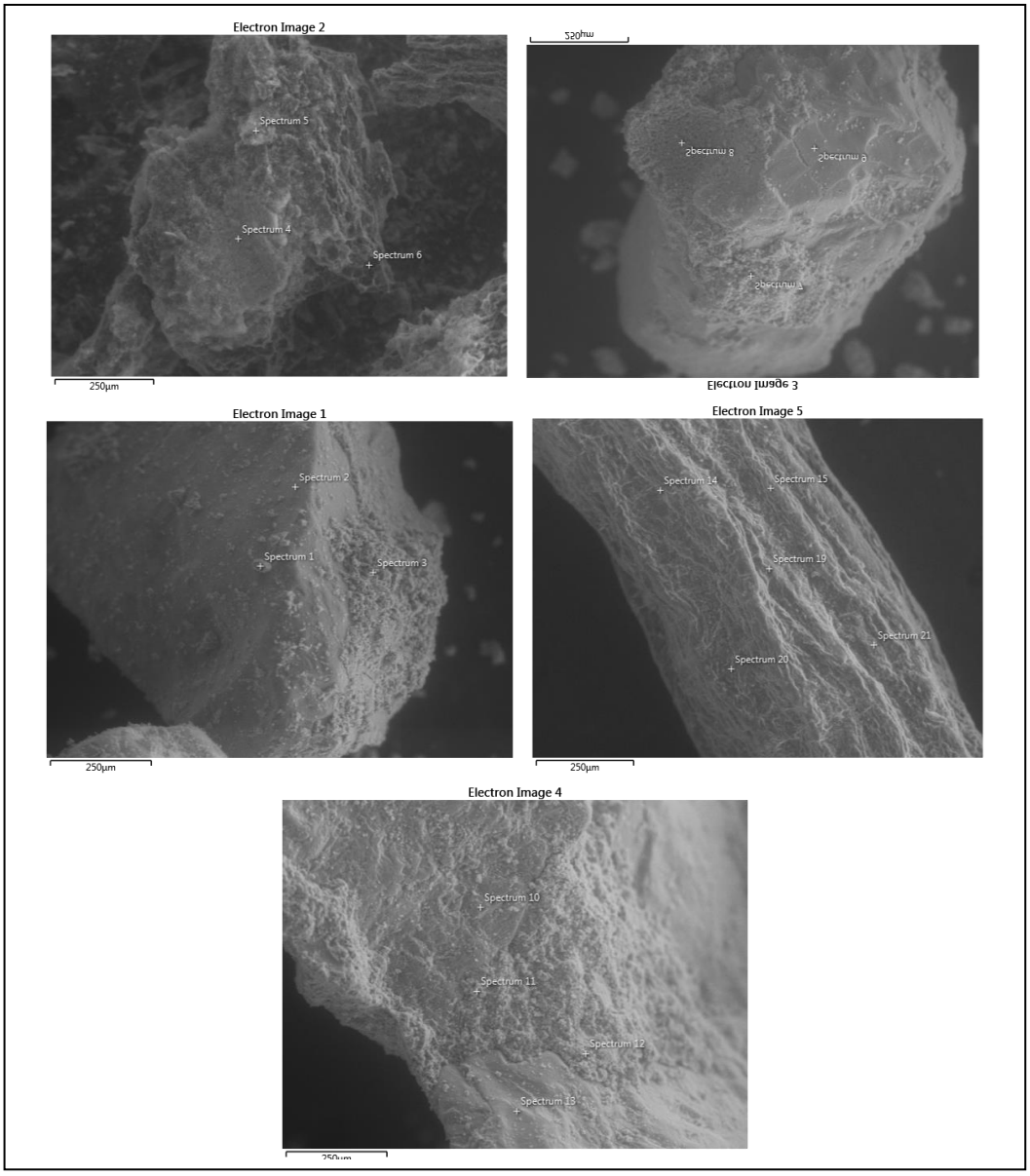

Figure 12: From top to bottom, and from left to right; (i) selected 600^{o}C burnt sample; (ii) crushed 600^{o}C burnt mortar mix; (iii) crushed oven dried mortar mix; (iv) oven dried sample; and (v) crushed conventional mix.

At 250µm, a more porous cellular structure observed for the crushed samples. For sample (i) selected 600^{o}C burnt sample, there is no pore opening at 250µm, and it is expected to fill the voids and capillaries thus increasing the workability of the mortar, which leads to; (ii) crushed 600^{o}C burnt mortar mix, where it is observed that the burnt seaweed sample helps to fill the gap in the voids between the sand and cement. This can increase the surface area and interlocking between the sand and cement. Compared to; (iii) crushed oven dried mortar mix, like the burnt sample where it fills the void, but the oven dried seaweed did not cover much void, and the interlocking between the cement and sand is much loosen. To support the discussion for the oven dried sample; (iv) the oven dried sample, from the EDX image shows that the sample is very brittle. This will lower the probability of the sample to fill the voids and increase the interlocking strength between the sand and cement. The sample is still surrounded by the cellulose cells which is very hard to break down. Lastly for the; (v) crushed conventional mix, the cement is filling the voids between the sand, which can increase the surface area and the interlocking strength.

4.5 BRUNAUER-EMMETT-TELLER (BET) TEST RESULT

Table 11: BET results for surface area.

Sample	Sand	Cement	600^{o}C burnt sample
BET Surface Area (m^2/g)	1.2564	1.4940	138.2451

The table above shows the Brunauer-Emmett-Teller (BET) test conducted on the samples; sand, cement, and 600^{o}C burnt sample. As the sample gets smaller, the higher the surface area. Therefore, the 600^{o}C burnt sample shows the highest surface area at 138.2451 m^2/g compared to the sand and cement. This shows that the 600^{o}C burnt sample is able to fill the spaces and voids between the sand and cement due to its big surface area. Thus, increasing the interlocking strength between the sand and cement, and as time goes by, it can increase the compressive strength.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Firstly, for the conclusion, this seaweed species, *Gracilaria Changii*, has a high moisture content of 89.25%. It is calculated by determining the dry weight of the sample and the weight after it has been washed.

For X-Ray Diffraction (XRD) test, 3 samples have been tested, 600^{o}C burnt sample, 700^{o}C burnt sample, and 800^{o}C burnt sample. This is to determine which sample has the most similarity to cement or cementitious property (CaO, SiO_2, Al_2O_3, Fe_2O_3, and S). The test has been carried out and the 600^{o}C burnt sample shows the highest similarity to the cementitious property. Therefore, the 600^{o}C burnt sample is proceeded to the next test.

For the next test, the compressive strength test. The oven dried seaweed sample and the selected 600^{o}C burnt seaweed sample have been mixed into mortars by replacing the cement in the mortar with different replacement percentage (0.1%, 0.5%, 1.0%, and 2.5%). A control mix design (without the sample added into the mix) also has been casted to compared the compressive strength at different testing dates (3-days, 7-days, 14-days, and 28-days). After 28 days, the results shown that the 0.5% of the selected burnt sample shows the highest compressive strength at 40.97 MPa, and to compare with the control mix which obtained 28.07 MPa. This shows that the 0.5% burnt sample can achieve a higher strength increment of 45.9%. Also, 0.1% burnt sample and 0.1% oven dried sample show greater value than the control mix, 36.61 MPa and 34.10 MPa respectively.

From the compressive strength test, Field Emission-Scanning Electron Microscope (FESEM) test has been carried out to support the findings. Samples taken for FESEM test are; (i) selected 600^{o}C burnt sample; (ii) crushed 600^{o}C burnt mortar

mix; (iii) crushed oven dried mortar mix; (iv) oven dried sample; and (v) crushed conventional mix. At 250µm, it is observed that there is no pore opening and it is expected to fill the gaps and voids and increase the workability of the mortar for the 600^{o}C burnt sample. When it is mixed into the mortar, the results obtained proved that the 600^{o}C burnt sample fill the spaces between the sand and cement thus increase the interlocking strength between them. For the oven dried sample, the EDX image shows that it has a brittle surface and could probably disrupts the workability of the mortar, which is then from the result when it is mixed in the mortar, the oven dried sample did not cover the spaces as much as the 600^{o}C burnt sample. This made the interlocking strength between the sand and cement is loosen and eventually show a low compressive strength result.

Lastly, for the Brunauer, Emmett and Teller (BET) test, it is also conducted to support the compressive strength test results. BET test is to determine the surface area of the samples; sand, cement, and 600^{o}C burnt sample. The results proved that the 600^{o}C burnt sample has the highest surface area of 138.2451 m^2/g compared to sand and cement, at 1.2564 m^2/g and 1.4940 m^2/g respectively.

Overall, the 600^{o}C burnt sample shows the highest similarity to cementitious property. Also, 0.5% of the 600^{o}C burnt sample has the highest compressive strength at 40.97 MPa, surpassing the control mix of 28.07 MPa, with an increment of 45.9%. The FESEM and BET tests were conducted to support the findings, which was proven that the 600^{o}C burnt sample fills the voids between the sand and cement while the oven dried sample did not cover as much. Also, that the 600^{o}C burnt sample has the highest surface area compared to the sand and cement which makes it easier to fill the gaps and increasing the interlocking strength of the sand and cement.

Therefore, using seaweed as a cement replacement material has shown a significant value in compression strength compared to conventional mortar. Therefore, green material is suitable to be used as cement replacement material for a sustainable development.

For future research similar to this project, it is recommended to conduct on different types of seaweed, cement, and acid treatment.

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APPENDICES

Table 12: Compressive strength at 3 days.

Cube Ref.	Date Cast	Date Test	Age (days)	Mass (g)	Max Load (kN)	Compressive Strength (MPa)
A1	21-Oct	24-Oct	3	253.4	56.18	22.47
B1	21-Oct	24-Oct	3	259.9	28.93	11.57
C1	21-Oct	24-Oct	3	261.3	26.70	10.68
D1	24-Oct	27-Oct	3	250.5	33.28	13.31
E1	24-Oct	27-Oct	3	258.0	24.95	9.98
F1	11-Nov	14-Nov	3	250.6	57.55	23.02
G1	11-Nov	14-Nov	3	255.1	30.88	12.35
H1	11-Nov	14-Nov	3	256.3	31.65	12.66
J1	11-Nov	14-Nov	3	258.4	23.15	9.26

Table 13: Compressive strength at 7 days.

Cube Ref.	Date Cast	Date Test	Age (days)	Mass (g)	Max Load (kN)	Compressive Strength (MPa)
A2	21-Oct	28-Oct	7	252.4	37.18	14.87
A3	21-Oct	28-Oct	7	271.1	59.05	23.62
A4	21-Oct	28-Oct	7	256.7	58.53	23.41
B2	21-Oct	28-Oct	7	261.2	40.85	16.34
B3	21-Oct	28-Oct	7	269.3	35.35	14.14
B4	21-Oct	28-Oct	7	266.7	26.58	10.63
C2	24-Oct	31-Oct	7	271.6	27.15	10.86
C3	24-Oct	31-Oct	7	263.3	26.08	10.43
C4	24-Oct	31-Oct	7	266.4	25.78	10.31
D2	24-Oct	31-Oct	7	265.5	50.93	20.37
D3	24-Oct	31-Oct	7	255.6	47.65	19.06
D4	24-Oct	31-Oct	7	260.8	55.15	22.06
E2	24-Oct	31-Oct	7	261.5	28.68	11.47
E3	24-Oct	31-Oct	7	266.6	31.35	12.54
E4	24-Oct	31-Oct	7	259.1	29.30	11.72
F2	11-Nov	18-Nov	7	261.9	45.88	18.35
F3	11-Nov	18-Nov	7	261.8	43.53	17.41
F4	11-Nov	18-Nov	7	264.2	38.78	15.51
G2	11-Nov	18-Nov	7	253.8	55.48	22.19
G3	11-Nov	18-Nov	7	253.9	45.65	18.26
G4	11-Nov	18-Nov	7	268.1	55.68	22.27
H2	11-Nov	18-Nov	7	254.6	35.80	14.32
H43	11-Nov	18-Nov	7	255.3	31.55	12.62
H4	11-Nov	18-Nov	7	261.5	48.10	19.24
J2	11-Nov	18-Nov	7	266.7	25.90	10.36
J3	11-Nov	18-Nov	7	264.0	38.33	15.33
J4	11-Nov	18-Nov	7	260.9	31.55	12.62

Table 14: Compressive strength at 14 days.

Cube Ref.	Date Cast	Date Test	Age (days)	Mass (g)	Max Load (kN)	Compressive Strength (MPa)
A5	21-Oct	04-Nov	14	264.5	58.83	23.53
A6	21-Oct	04-Nov	14	267.2	58.23	23.29
A7	21-Oct	04-Nov	14	259.3	54.03	21.61
B5	21-Oct	04-Nov	14	268.6	92.45	36.98
B6	21-Oct	04-Nov	14	269.7	69.25	27.7
B7	21-Oct	04-Nov	14	266.2	61.53	24.61
C5	24-Oct	07-Nov	14	261.2	51.78	20.71
C6	24-Oct	07-Nov	14	269.3	38.53	15.41
C7	24-Oct	07-Nov	14	266.7	43.30	17.32
D5	24-Oct	07-Nov	14	271.3	49.03	19.61
D6	24-Oct	07-Nov	14	261.8	50.70	20.28
D7	24-Oct	07-Nov	14	258.1	44.80	17.92
E5	24-Oct	07-Nov	14	271.1	34.28	13.71
E6	24-Oct	07-Nov	14	259.8	43.60	17.44
E7	24-Oct	07-Nov	14	260.2	29.70	11.88
F5	11-Nov	25-Nov	14	256.2	43.40	17.36
F6	11-Nov	25-Nov	14	266.4	83.28	33.31
F7	11-Nov	25-Nov	14	271.8	90.70	36.28
G5	11-Nov	25-Nov	14	262.3	34.80	13.92
G6	11-Nov	25-Nov	14	256.2	51.63	20.65
G7	11-Nov	25-Nov	14	274.7	75.80	30.32
H5	11-Nov	25-Nov	14	271.2	48.00	19.2
H6	11-Nov	25-Nov	14	265.9	38.35	15.34
H7	11-Nov	25-Nov	14	266.7	31.55	12.62
J5	11-Nov	25-Nov	14	266.9	35.98	14.39
J6	11-Nov	25-Nov	14	269.1	34.20	13.68
J7	11-Nov	25-Nov	14	268.7	37.30	14.92

Table 15: Compressive strength at 28 days.

Cube Ref.	Date Cast	Date Test	Age (days)	Mass (g)	Max Load (kN)	Compressive Strength (MPa)
A8	21-Oct	18-Nov	28	255.4	54.15	21.66
A9	21-Oct	18-Nov	28	265.2	89.53	35.81
A10	21-Oct	18-Nov	28	254.1	66.88	26.75
B8	21-Oct	18-Nov	28	257.5	71.85	28.74
B9	21-Oct	18-Nov	28	265.3	104.45	41.78
B10	21-Oct	18-Nov	28	266.5	79.45	31.78
C8	24-Oct	21-Nov	28	278.1	28.15	11.26
C9	24-Oct	21-Nov	28	266.3	24.35	9.74
C10	24-Oct	21-Nov	28	272.1	30.80	12.32
D8	24-Oct	21-Nov	28	259.1	42.85	17.14
D9	24-Oct	21-Nov	28	258.8	56.58	22.63
D10	24-Oct	21-Nov	28	264.4	28.28	11.31
E8	24-Oct	21-Nov	28	268.5	24.58	9.83
E9	24-Oct	21-Nov	28	255.1	48.90	19.56
E10	24-Oct	21-Nov	28	274.5	69.43	27.77
F8	11-Nov	09-Dec	28	261.9	56.88	22.75
F9	11-Nov	09-Dec	28	261.9	95.33	38.13
F10	11-Nov	09-Dec	28	264.2	87.73	35.09
G8	11-Nov	09-Dec	28	253.8	102.18	40.87
G9	11-Nov	09-Dec	28	253.9	105.55	42.22
G10	11-Nov	09-Dec	28	268.1	99.58	39.83
H8	11-Nov	09-Dec	28	269.1	55.90	22.36
H9	11-Nov	09-Dec	28	270.6	43.55	17.42
H10	11-Nov	09-Dec	28	271.6	43.88	17.55
J8	11-Nov	09-Dec	28	269.4	46.50	18.6
J9	11-Nov	09-Dec	28	265.9	48.43	19.37
J10	11-Nov	09-Dec	28	272.5	35.53	14.21

Figure 13: Washed seaweed

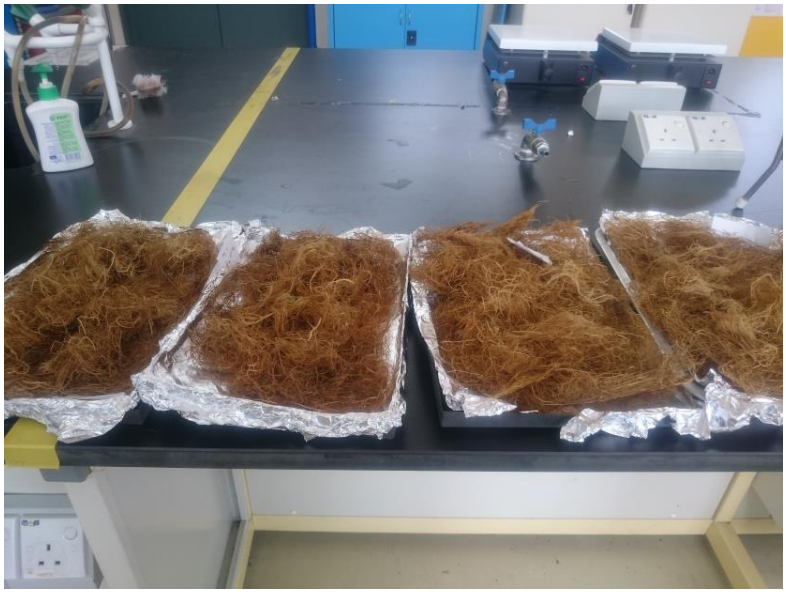

Figure 14: Oven dried seaweed

Figure 15: Sieved oven dried seaweed at 125µm.

Figure 16: 600^{o}C burnt sample

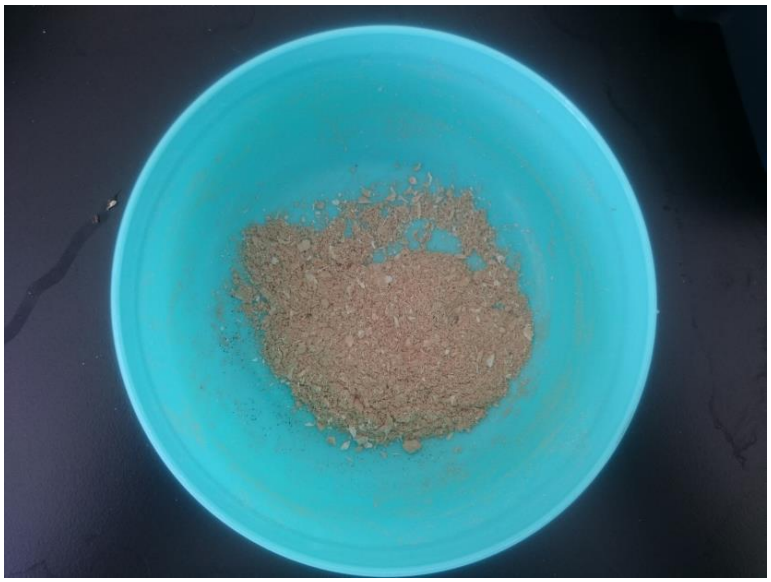

Figure 17: 700^{o}C burnt sample

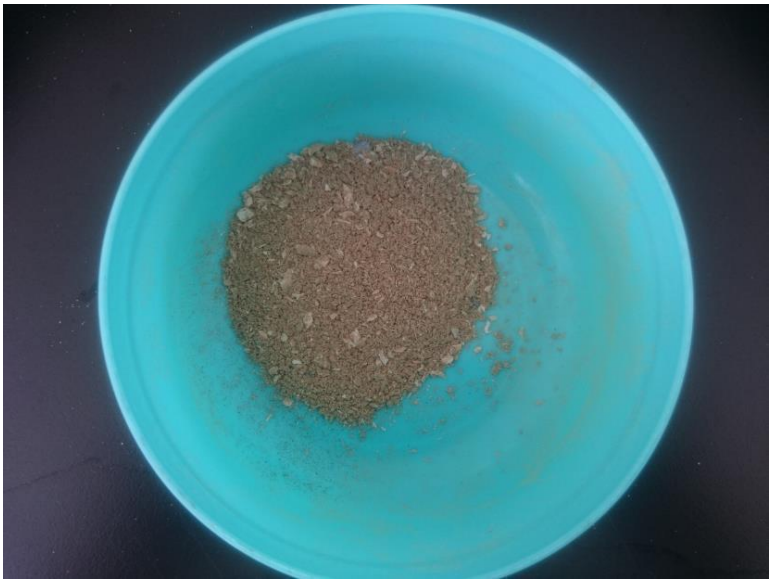

Figure 18: 800^{o}C burnt sample

Figure 19: Mortar casted into mold

Figure 20: Curing of mortar cubes in curing tank

Figure 21: Compressive strength test of the mortar

Figure 22: Crushed mortar cubes