PERFORMANCE OF GEOPOLYMER CONCRETE IN AGGRESSIVE ENVIRONMENT

By

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17224

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

____

(Ir. Dr, Idris bin Othman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, 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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MUHAMMAD FARID BIN MOHD SALLEH

ABSTRACT

The consumption of cement had caused pollution to the atmosphere. The cement industry is responsible for significant CO_2 emissions because of its production. The carbon dioxide gas production is based from the process of burning large quantities of fuel and inherent to the basic process of calcinations of limestone. The process of making Portland Cement basically produce a large amount of CO_2 emissions and other greenhouse gases.

Ordinary Portland Cement (OPC) are generally not resistant to exposure of acid and sea water. In terms of strength and durability, Portland cement has proved that its cannot stand in such exposure conditions during its service life span. The development of geopolymer concrete with a combination of sodium hydroxide and sodium silicate, offers a promising alternative OPC. Therefore, this research aims to identify the performance of geopolymer concrete in aggressive environment.

The specimens were exposed to 5% of sulphuric acid, sodium chloride and distilled water. The processing of geopolymer using fly ash and alkaline activator solution by using different moles concentration of sodium hydroxide of 8M and 11M. The concrete will be cured in oven for 7 days at 60 $^{\circ}$C and then will be immersed separately in sulphuric acid, sodium chloride and distilled water until 35 days. The compressive strength and change in density will be examined after 7, 14, 21 and 35 days to test its behavior in term of durability and strength.

Based on the result obtained, it can be concluded that specimens with 11M of NaOH concentration has a better compressive strength when exposed to aggressive environment. The density of 11M specimens also higher than 8M specimens. The regression data of strength and density showed a uniform polynomial line as the density increase, the compressive strength also increase. Hence, the objective of the research is achieved.

ACKNOWLEDGEMENT

I would like to express my special gratitude to my Project Supervisor, Ir. Dr. Idris Othman for his guidance and support provided throughout this final year project. He has keep me on the correct path and allowing me to carry out my project.

I express my deepest thanks to laboratory technician and post graduate students who help me during this research. They have taught me to do the experiments in correct ways and giving advise while arranged all facilities and equipment for me to do the experiments.

I also would like to extend my appreciation to my family and friend who have given a full support and encouragement during this project and help on difficult situations. I will use this gained knowledge and skills as the best possible ways.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Ordinary Portland Cement, OPC is one of the main component in concrete mixtures. Concrete is widely used as a construction material in the world. The cement industry is responsible for significant CO_2 emissions because of its production. The consumption of cement industry had caused pollution to the atmosphere. The alternative to reduce CO_2 emissions is by using cement replacement material to substitute the function of binder in concrete ingredients.

Geopolymer fly ash-based concrete is one of the alternative that could be used as cement replacement material. Geopolymer concrete is made up of fly ash, sand, and alkaline solution of sodium hydroxide, NaOH and sodium silicate, Na_2O_3Si. It can play an important in its environmental control of greenhouse effects and contribute to reduction of carbon dioxide emission from cement production.

Geopolymer concrete also have been reported as being acid resistant and thus promising such an alternative binder for sewer pipe manufacture. Looking on view of Malaysia weather, there is an acidic rain on and off, and this rain will be in contact with structures on the ground and cause deterioration in concrete. In terms of marine environment, geopolymer concrete is subjected to seawater for coastal structures, jetty or building nearby the sea.

This research will conduct a study on the performance of geopolymer concrete in aggressive environment. The aggressive environment can be defined as acidic and marine exposure. Concrete that in contact with these two conditions will experience chemical reactions involving chlorides, sulfates, magnesium and acid ions. The study will evaluate the durability and strength of geopolymer concrete in various condition.

1.2 Problem Statement

The cement industry has been making a significant production of CO_2 gas emissions that will cause pollution to the atmosphere. The carbon dioxide gas production is based from the process of burning large quantities of fuel and inherent to the basic process of calcinations of limestone. The process of making Portland Cement basically produce a large amount of CO_2 emissions and other greenhouse gases.

Ordinary Portland Cement (OPC) are generally not resistant to exposure of acid and sea water. When a concrete is subjected to these two conditions, chemical reaction between cement and ions in acid and seawater will cause the decalcification of Calcium-Silicate-Hydrate, C-S-H. As a result, the interior concrete layer will expose to deterioration.

In terms of strength and durability, Portland cement has proved that its cannot stand in such exposure conditions during its service life span. The development of geopolymer concrete with a combination of sodium hydroxide and sodium silicate, offers a promising alternative OPC. Geopolymer basically rich in silicon and aluminum as the source materials for geopolymer is alumino-silicate based and act as a binder with a high strength and better durability.

However, very few studies have assessed performance of geopolymer concrete in term of strength and workability when its subjected to aggressive environment. Therefore, the ability of geopolymer concrete when exposed to aggressive environment still in doubt to be commercialize for industry uses.

1.3 Objectives and Scope of Study

Objectives

The objective of this research is to evaluate the performance of geopolymer concrete in aggressive environment by doing a lab test to achieve the following objectives:

a) To determine the durability of geopolymer concrete when exposed to aggressive environment.

b) To determine the strength of geopolymer concrete when exposed to aggressive environment.

c) To establish an equation of the relationship between durability and strength of geopolymer concrete.

Scope of Study

This research focused on the performance of geopolymer concrete and testing its behavior in term of durability and strength. Fly ash-based geopolymer concrete was exposed to 5% of hydrochloric acid, sodium chloride, and distilled water. The geopolymer concrete will be cured in oven for 7 days at 60 ˚C and then will be immersed in hydrochloric acid, sodium chloride and normal water until 35 days. The compressive strength and change in density will be examined after 7, 14 21, and 35 days.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

On this chapter, the terminology and chemistry of geopolymer is presented and also the previous studies of geopolymers.

2.2 Origin of Geopolymer

Geopolymer was introduced by Davisdovits in 1978. The research was believed to reduce carbon dioxide emission to the atmosphere as the cement properties which can produced large number of carbon dioxide while processing it. Geopolymer is family from inorganic material which have the similarities to natural materials (Shankar H. Sanni & Khadiranaikar, R.B, 2012).

Material which have properties of silicon(Si) and aluminium(Al) in form of amorphous might be the alternative source for geopolymer. Low calcium ASTM Class F of fly ash and any natural Al-Si material with the combination of alkaline activator has been found as source materials (Shankar H. Sanni & Khadiranaikar, R.B, 2012).

Van Jaarsveld et al (1997) have done fundamental research into minerology of any individual materials mineral forming geopolymers and the chemical mechanics that believed to be gel formation reaction in geopolymeric system. If clays and fly ash were combined together, its believed that the starting material will not complete as the final hardened is formed.

In present research, many cases have found that only small amount of silica and aluminium present during the reaction on particle surfaces to solidify the whole mixtures. Therefore, the surface reaction is important to make sure that the particles will dissolved into final geopolymeric structures.

There are three steps in geopolymerization scheme which consists of dissolution, reorientation and solidification as shown in figure below.

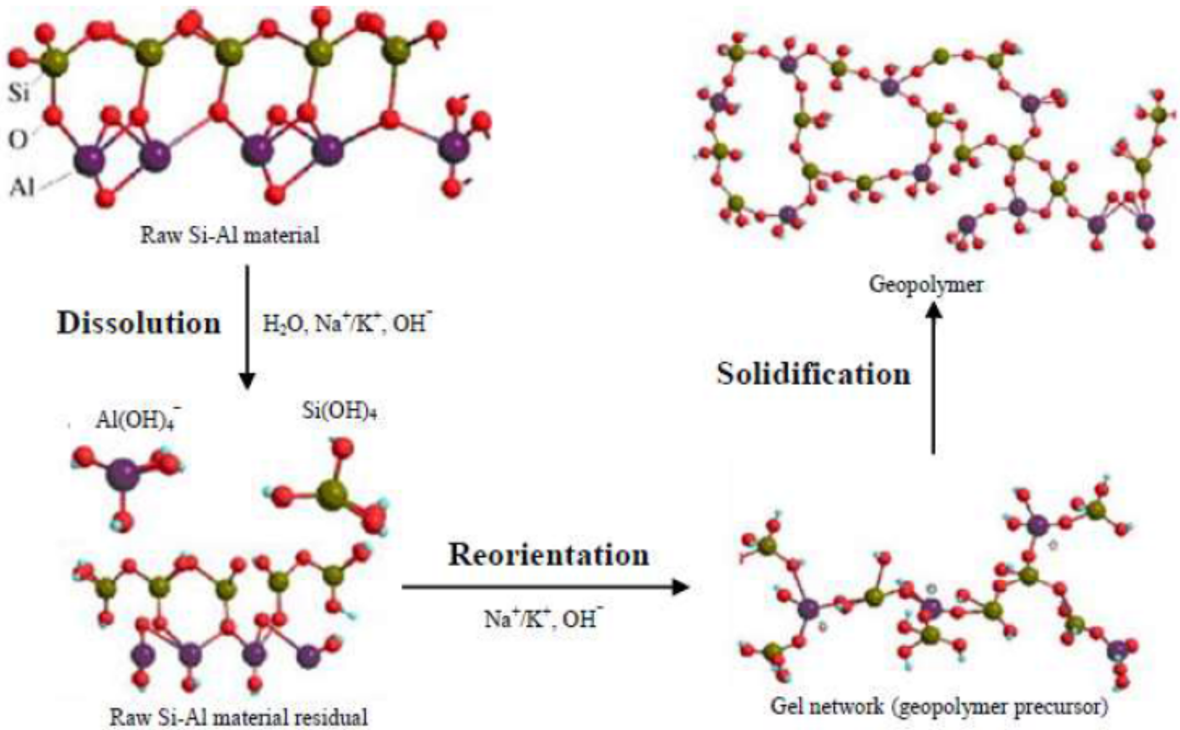


Figure 1: Geopolymerization Scheme

For the first step, silica and aluminium material in contacts with the alkaline activator and called as dissolution process where Si and Al species are presented. The concentration of alkaline activator affects the formation of Si and Al species as well as the mixing rate and time, type of metal cation presence such as Sodium or Potassium and also Si-Al raw material properties.

The second step is reorientation. This is where the dissolved Si and Al are diffused into oligomers formed. When it formed to oligomers at the aqueous phase, the condensation process is occurred and form a large network of a gel. After the dissolved aluminium and silica is removed from the surface materials, the reactive leaching so Al and Si species from the raw material is occurred.

On this step, the essential of stirring of time and intensity is one of the factors affected. The removal of dissolved Si and Al material from the surface of raw materials is depends on how the intensive stirring and leaching period maximization and the boundary will break kinetically when Si and Al material is in gel phase.

For the last step, the gel network will continue to rearrange and reorganize its structures until the connectivity of the gel network is maximize or become semi-crystalize three dimensional alumino silicate formed and called as geopolymeric reaction. On this state, the temperature and air circulation is the main factors to determine the properties of the geopolymer formed.

2.3 Source Materials and Alkaline Liquids

For geopolymer components, there are two main ingredients that important called as source material and alkaline activator. The source material must be rich of Silicon(Si) and Aluminium(Al) because it's a based product for geopolymer. The source material could be from the natural minerals such as kaolite or clays or those who contain empirical formula contains silicon, aluminium and also oxygen. (Davidovits study, as cited in Wallah and Rangan, 2006).

The waste product that can be used to formed geopolymer can be collected and namely as fly ash, slag, silica fume, or red mud. There products could be the source material to make geopolymer depends upon its availability, costs, and type of application used and the specific demand of the end users while the alkaline activator usually available as soluble alkali metal from potassium and sodium based.

Xu and Van Deventer's study (as cited in Wallah and Rangan, 2006) have done a research on wide range to find a material that rich with alumino silicate in order to make geopolymers. The research involved around sixteen alumino silicate materials which cover the ring, framework, and chain of crystal structure groups.

The wide range of natural alumino silicate minerals can provide a potential source in order to synthesize the geopolymers. For alkaline activator, the uses of potassium and sodium hydroxide can increase the geopolymeric reaction. Based on the research, the potassium hydroxide showed an excellent result in properties of compressive strength and the extent of dissolutions.

Fly ash and slag is the potential material among the waste or by-product which can be used as source materials. The previous research had reported these two products could be used as source material by some researchers. In order to make fire blast resistant, geopolymer with combination of granulated blast furnace slag performed better.

Van Jaarsveld et.'s study as cited in Wallah and Rangan (2006) said that the properties of particles size, alkali metal content, calcium content, and the origin of the fly ash is the factors affecting the geopolymer system. In his studies, it also said the calcium content in fly ash play a significant role in order to develop the strength as the larger calcium content might resulted in excellent strength development and good compressive strength.

The optimal bind properties of the geopolymer, the fly ash which is main source material, must have the lower calcium content and other characteristic as well because the unburned material lower than 5% of Fe2O3 content and should not be higher than 10%, where 40% - 50% of reactive silica content, and 80 – 90% particles is lower in size than 45mm and high content of vitreous phase. (Fernández-Jiménez & Palomo's study as cited in Wallah and Rangan, 2006).

Gourley's study as cited in Wallah and Rangan (2006) stated the presence of calcium content in fly ash with large quantities could affect the polymeric process ans setting rate as well as the alters of microstructure. Then, it can be concluded that the uses of low calcium fly ash (ASTM Class F) is more preferable and excellent choice rather than (ASTM Class C) fly ash as its content high calcium to make geopolymers.

2.4 Fields of Applications

Based on Davidovits's study as cited in Wallah and Rangan (2006), geopolymer can widely use in industries of application such as automobile, civil engineering and plastic industries. The uses of geopolymer is depend on what type of chemical structures in application going to use and it's based on atomic ratio silica aluminium in the polysialate.

Davidovits's study as cited in Wallah and Rangan (2006) stated the classification of application for geopolymer based on the silica aluminium ratio. Table below showed the application that can be used for geopolymer in civil engineering field. The low ratio will form a rigid geopolymer while the higher ratio more than 15 provides a polymeric character og geopolymer.

Toxic waste is one of the potential industries that uses of geopolymer because the zeolitic components in geopolymer have the ability to absorb the toxic waste chemical in the field of toxic uses. The geopolymer system has shown a good use in the industries in order to reduce the carbon dioxide emission while served to the environment.

Si:Al ratio	Applications
1	- Bricks - Ceramics - Fire protection
2	- Low CO_2 cements and concretes - Radioactive and toxic waste encapsulation
3	- Fire protection fibre glass composite - Foundry equipments - Heat resistant composites, 200°C to 1000°C - Tooling for aeronautics titanium process
>3	- Sealants for industry, 200°C to 600°C - Tooling for aeronautics SPF aluminium
20 - 35	- Fire resistant and heat resistant fibre composites

Table 1: Applications of geopolymer

2.5 Properties of Geopolymers

Properties of geopolymer has been reported to have a high early strength, a good freeze-thaw resistance, resist to sulfate, resist to corrosion, resist to acid, an excellent resist to fire, and have no damage while react with the aggregates.

In term of heat and fire resistance, it has been proved that geopolymer can withstand in such environment. The ordinary Portland cement has showed it only withstand on 300°C while geopolymer basically can withstand heat up to 600°C (Davidovits's study as cited in Wallah and Rangan, 2006). Based on the previous research, it can be proven that geopolymer has excellent low shrinkage when compared to ordinary Portland cement.

As studied had been done by Davidovits, he stated that geopolymer is safe to react the aggregates with high alkali concentration while the ordinary Portland cement will generate a dangerous reaction if react with high alkali concentration. Based on the standard of ASTM C227, the bar expansion test showed the geopolymer cement with high alkali concentration did not generate any dangerous alkaline aggregates reaction like ordinary Portland cement did.

One of the geopolymer properties is being acid resistant because compared to Portland cement, it is relying on lime while geopolymer does not rely on it and does not dissolved by acidic solutions. As it has been proved by exposing the geopolymer to 6% of sulfuric acid and chloric acid, the Portland cement were unable to withstand in such condition whre the calcium alumina cement has lost weight around 30 -60% while geopolymer relatively stable with the reducing weight lost around 5-6%.

Some recently published papers (Bakharev; Gourley & Johnson; Song et. al.'s study as cited in Wallah and Rangan, 2006) stated that the results obtain on research of geopolymer properties. By observing the weight loss and compressive strength after acid exposure, these researchers conclude that geopolymer have better properties.

2.2 Summary of Previous Research

Based on the previous research, the key statements and gaps were found and have been summarized as per below table 1:

Researcher	Key Statement	Gaps
• Ilyas Nurhadi (2015)	1. Geopolymer concrete with 8M concentration NaOH has better compressive strength in sulfate attack. 2. Concrete that cure in high temperature has more weight while in low temperature has loss some weight.	1. Curing temperature can be varying in order to find optimum temperature. 2. Test another chemical attack that may occur in marine environment.
• Michael Terefe Woldemariam (2014)	1. The increase in the percentage inclusion of OPC resulted in a lower compression strength and fire resistance 2. The resistance to alkali penetration has also decreased with the increase OPC percentage inclusion.	1. Future investigations should be done on these properties by adding water in the system.

Researcher	Key Statement	Gaps
• Mr. K. Madhan Gopal (2013) • Mr. B. Naga Kiran (2013)	1. Geopolymer concrete resist better in acid attack rather than conventional concrete. 2. Percentage loss on compressive strength in geopolymer is lower rather than conventional concrete in all tests.	1. Suggest to do experiment on seawater exposure. 2. Different test to check on geopolymer concrete behavior.
• Shankar H. Sanni (2012) • Khadiranaikar R. B. (2012)	1. Variable of alkaline concentration in geopolymer resulted in different deterioration when immersed in sulfuric acid. 2. Reduction on strength and weight is significantly low for geopolymer concrete when specimens exposed to acid condition.	1. Varying the ratio of sodium hydroxide and sodium silicate for geopolymer mix design. 2. Exposed to higher concentration of acid and sulphate solution.

Researcher	Key Statement	Gaps
• S. Kumaravel (2013) • K. Girija (2013)	1. The 12 M concentration of NaOH in geopolymer concrete showed the better result in reduction of weight instead of 8 M, 10 M, and 12 M. 2. The 12 M concentration of NaOH in geopolymer concrete showed the lowest value in reduction strength instead of 8 M, 10 M, and 12 M.	1. Varying the NaOH concentration in geopolymer concrete mix design. 2. Suggest to used different test to check geopolymer concrete behavior.
• Srinivas K S (2015) • M T Prathap Kumar (2015) • W P Prema Kumar (2015)	1. The geopolymer concrete attains target compressive strength at much less curing period of 14 days under sun light curing compared with conventional concrete. 2. Significant loss of mass is indicated to occur for conventional concrete when compared to geopolymer concrete after being exposed to five percent of acid solution.	1. Used different method of curing process. 2. Suggest to use higher concentration of acid exposure.

Researcher	Key Statement	Gaps
• K. Chinnasubbarao (2015) • G. Shani Priyanka (2015)	1. The geopolymer concrete have a better strength compared to conventional concrete when exposed to acid and sulphate attack 2. Geopolymer concrete less change in weight when exposed to sulphuric acid, sodium sulfate and sodium chloride 3. Geopolymer concrete exhibits higher tensile strength compared to conventional concrete, which is suitable for structural applications.	1. Varying in the concentration of acid and sulphate exposure. 2. Conduct other test to evaluate the geopolymer concrete ability. 3. Used other size of beam and column to analyze tensile strength of geopolymer concrete.
• D. V. Reddy (2011) • J-B Edouard (2011) • K. Sobhan (2011) • S.S. Rajpathak (2011)	1. Geopolymer concrete have better corrosion resistant compared to conventional concrete. 2. Geopolymer concrete possess high early compressive strength compared to conventional concrete	1. Conduct another test to check on durability of geopolymer concrete. 2. Try another curing method of geopolymer concrete.

Table 2: Previous Researchers Findings

CHAPTER 3

METHODOLOGY

3.1 Project Sequence

The project sequence will be followed as shown in the figure

Figure 2: Project sequences

3.2 Experiment Procedures

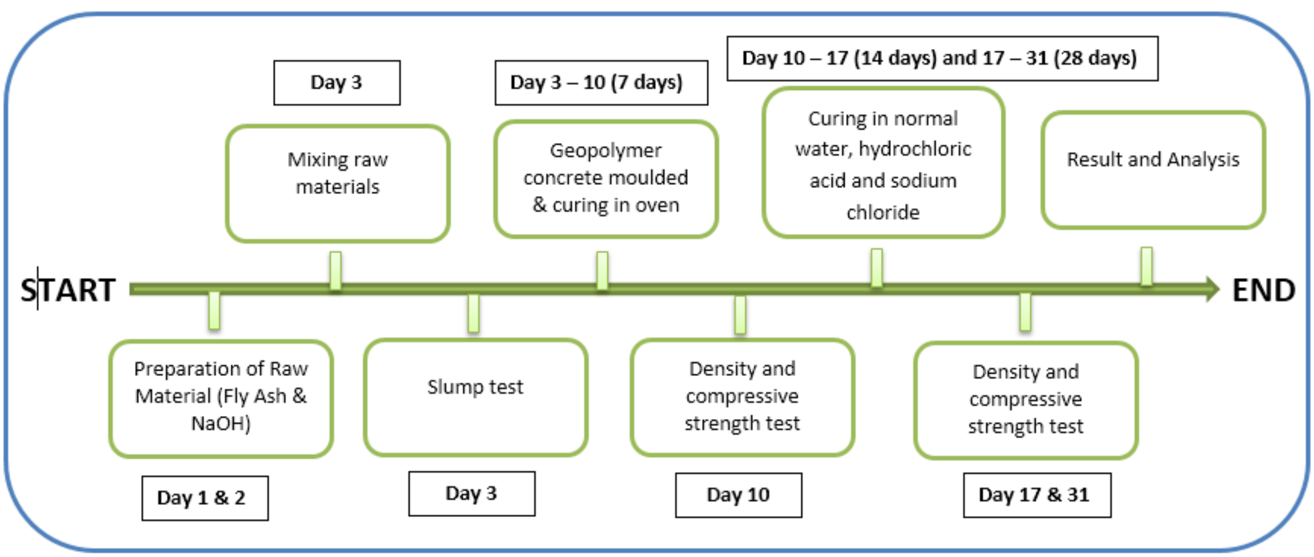


Figure 3: Experiment Procedures

3.3 Materials and Method

3.3.1 Preparation of Raw Materials

This research had been done with experiment by using a low calcium fly ash (ASTM Class F) as the main component in geopolymer ingredients. The low calcium fly ash has a chemical compostion shown in the table below. The fly ash is collected from the Manjung power station, Lumut, Perak, Malaysia

Oxides	Percent by mass
Silicon dioxide	51.3
Aluminium oxide	30.1
Ferric oxide	4.57
Calcium oxide	8.73
Phosphorus pentoxide	1.6
Sulphur trioxide	1.4
Potassium oxide	1.56
Titanium dioxide	0.698

Figure 4: Chemical composition of Fly Ash

The alkaline ingredients to be mix with fly ash is used with the combined solution of sodium hydroxide and also sodium silicate. Solution of sodium silicate is ready and to be mixed with sodium hydroxide later.

The sand used is fine aggregates and had being well graded where the fine aggregates has a specific gravity of 2.61 respectively and maximum size of 5mm. The aggregates are in saturated surface dry condition.

3.3.2 Mix Design and Mixing

In order to mix the ingredients and become geopolymer, the standard procedure of mixing is followed. The proportion of geopolymer has been done according to the mix design. Below are the steps of mixing procedures.

1) The sodium hydroxide is in pallet formed. It has been dissolved with distilled water one day before mixing. The sodium hydroxide pallets basically are 99% pure and the solution prepared is 8M and 11M.

2) The materials are prepared according to the ingredients of mix design. The fine aggregates are weigh properly for the optimum volume of the mortar to be prepared.

3) Two alkaline solution is prepared where sodium hydroxide and sodium silicate is measured by the optimum volume needed.

4) For the last step, all the ingredients will be insert into concrete mixer and set the time for mxing.

Figure 5: Mixing machine

Proportion of Geopolymer Mortar

For this research, the proportion of geopolymer mortar is shown below. Basically, all mortars have same amount of fine aggregates, fly ash, sodium hydroxide and sodium silicate volume. The different in mix design is the concentration of sodium hydroxide as the comparison of two concentration will resulted in different properties of geopolymer.

Proportion for six cubes of mortars:

- Fine aggregates 1200 grams
- Fly ash (ASTM Class F) 600 grams
- Sodium Hydroxide (NaOH) 75 grams
- Sodium Silicate (Na_2SiO_3) 225 grams

3.3.3 Casting and Curing

The mortar cubes are cast into mould after mixing. These mortars will immediately pour into the moulds prepared. The dimensions of mortar mould are 50mm x 50mm x50mm. Then, geopolymer is allowed to settle and go through curing process in the oven for 7 days. After that, 3 samples of geopolymer concrete will perform density check test and compressive test. Another samples will be immersed in hydrochloric acid, sodium chloride, and normal water will be going tested again for 14, 21, and 35 days.

Figure 6: Moulding and Curing in Acid, Salt, and Normal water

3.3.4 Testing

Durability Test (Check in Density)

Density is measured as one of the durability test. Density basically can be defined as solidity of the mortar. Measurement of density is simplified as the mass over volume ratio. To check the density of the geopolymer mortar, the weight of geopolymer mortar will be evaluated after curing and divided with the volume.

Compressive Strength Test

Compressive strength test is one of the test that evaluate the properties of geopolymer. The maximum force applied on the geopolymer indicates the maximum force that geopolymer can attained in such condition. For this test, it is performed according to BS EN 12390-3 (2009) by using a digital compression with capacity of 2000kN. The compressive test of geopolymer is performed on the 7,14,21, and 35 days after exposed to aggressive environment.

Figure 7: Compressive Strength Testing Machine

3.4 Gantt Chart/Key Milestone

Gantt Chart below shown the timeline of FYP 1 and FYP 2. This final year project should be finished within 2 semesters. FYP 1 will start on May 2016 and completion of final year project should be at the end of December 2016.

FYP I:

Planning Activities	Weeks													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic	■	■												
Preliminary Research Work			■	■	■	■	■							
Submission of Extended Proposal								■						
Proposal Defense									■					
Project works continue										■	■	■		
Submission of Interim Draft Report													■	
Submission of Interim Report														■

Table 3: Project Gantt chart for FYP I

FYP II:

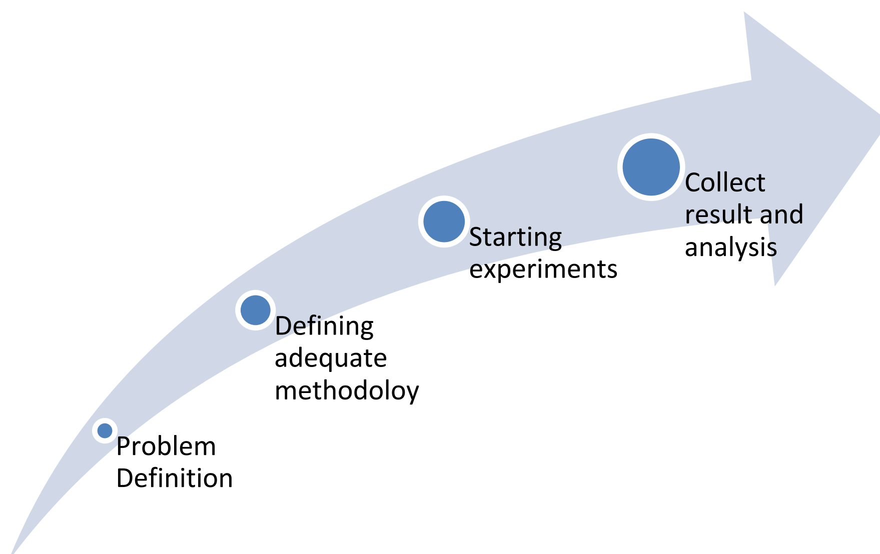
Planning Activities	Weeks													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project work continues	■	■	■	■	■	■	■	■	■	■	■	■		
Submission of Progress report							■							
Pre-SEDEX										■				
Submission of Draft Final report											■			
Submission of Technical Paper												■		
Viva													■	
Submission of Dissertation														■

Table 3: Project Gantt chart for FYP II

KEY MILESTONE:

Key milestones for Final Year Project is define as follows:

➢ Problem definition:	Week 3 (fyp 1)
➢ Defining adequate methodology	Week 7 (fyp 1)
➢ Starting experiments	Week 2 (fyp 2)
➢ Collect result and analysis	Week 9 (fyp 2)



CHAPTER 4

RESULTS AND DISCUSSION

4.1. Durability Test results

Durability of geopolymer mortar is determined by change in density. The density of specimens was measured after 7 days cured in oven and 14, 21 and 35 days exposed to the aggressive environment. The density is compared between 11M and 8M concentration of NaOH. The bar chart below showed the comparison of density in different exposure of aggressive environment.

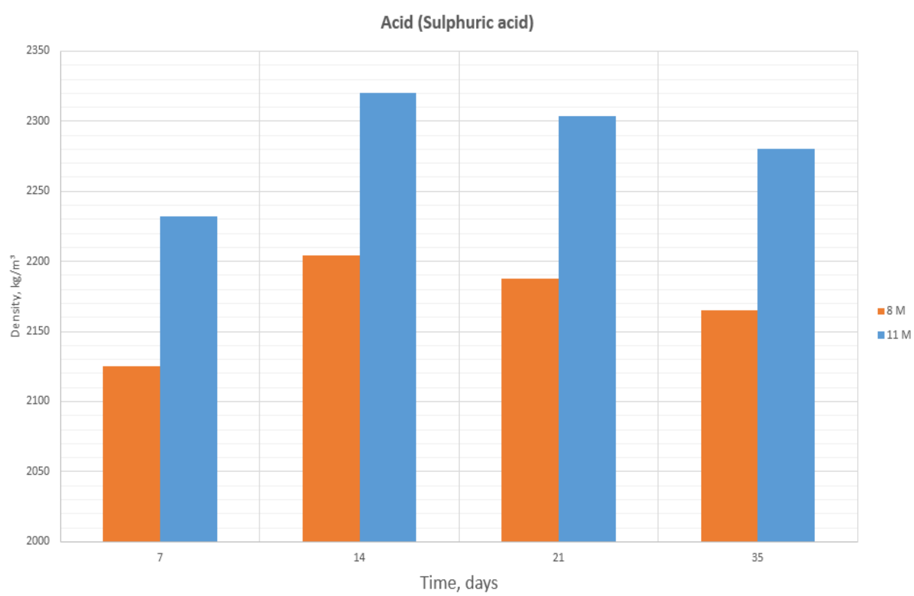


Figure 8: Density comparison in acid environment

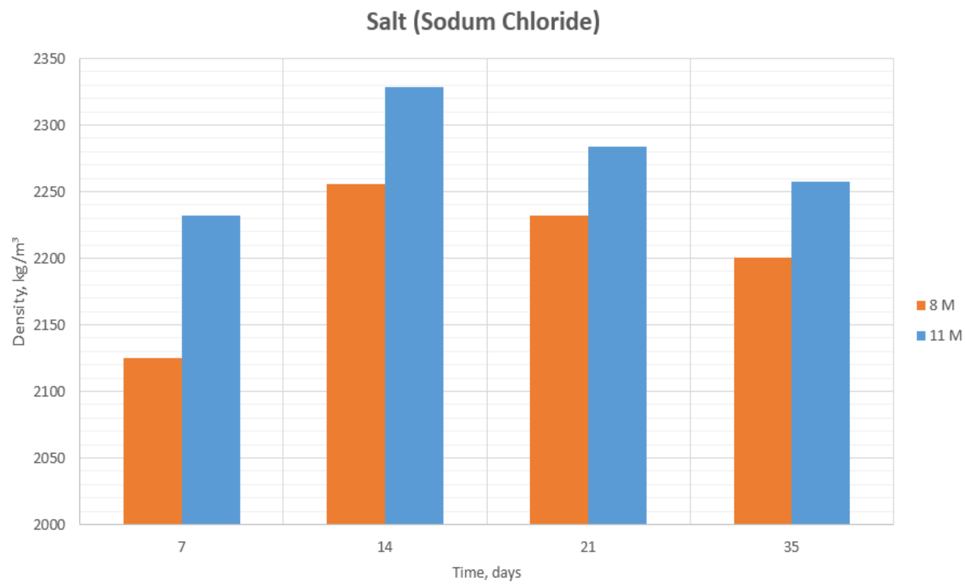


Figure 9:Density comparison in marine environment

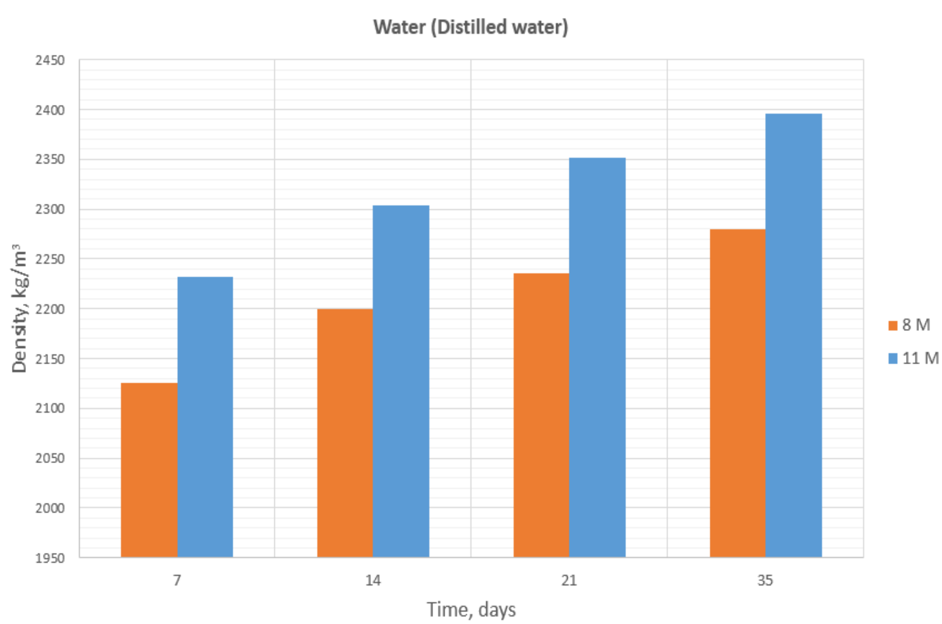


Figure 10:Density comparison in normal environment

Based on the result above, its showed the specimens immersed in distilled water have increasing in density while the specimens exposed to acid and salt have increasing density on 14 days, but starting to decrease at 21 days because of acid and chloride attack. The density increase on 14 days because no water present during curing in oven, but after put it in those solution, the density increase as water one of the component that affect and give strength to concrete.

4.2 Compressive Strength

The compressive strength of the concrete samples was measured using a ASTM C39 test method. The compressive strength was determined after specimens were cured in oven for 7 days and exposed to aggressive environment on 14, 21 and 35 days. The result of compressive strength is shown in figure below.

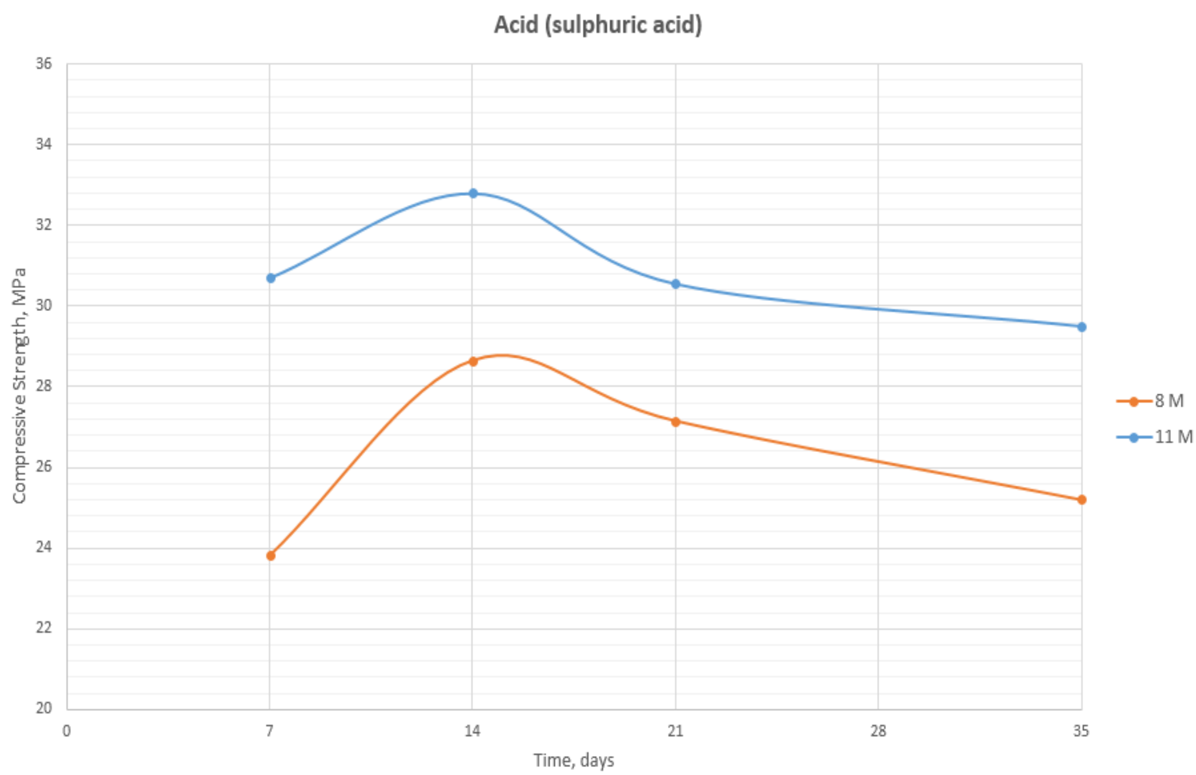


Figure 11: Strength comparison in acid

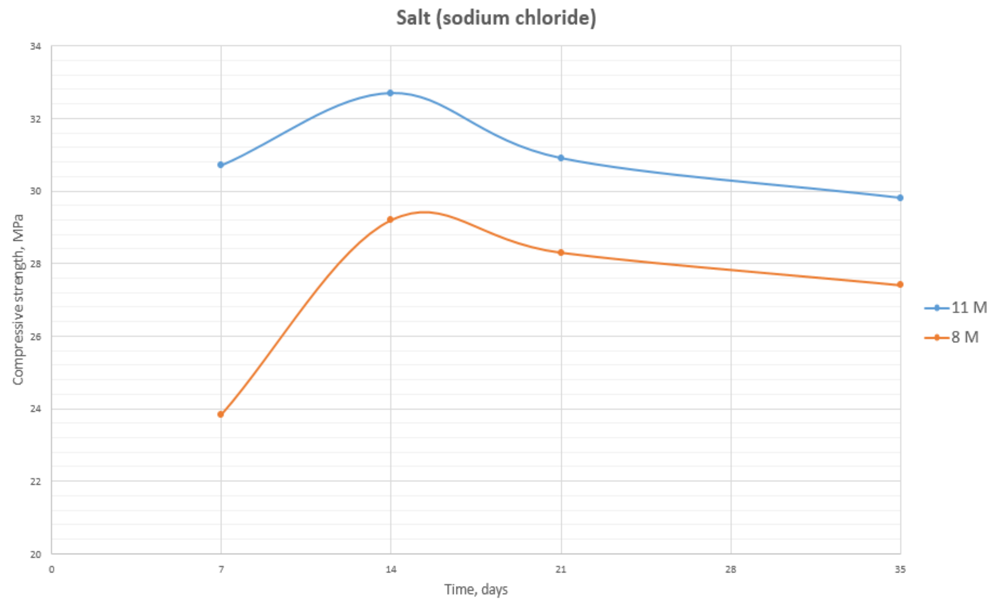


Figure 12: Strength comparison in salt

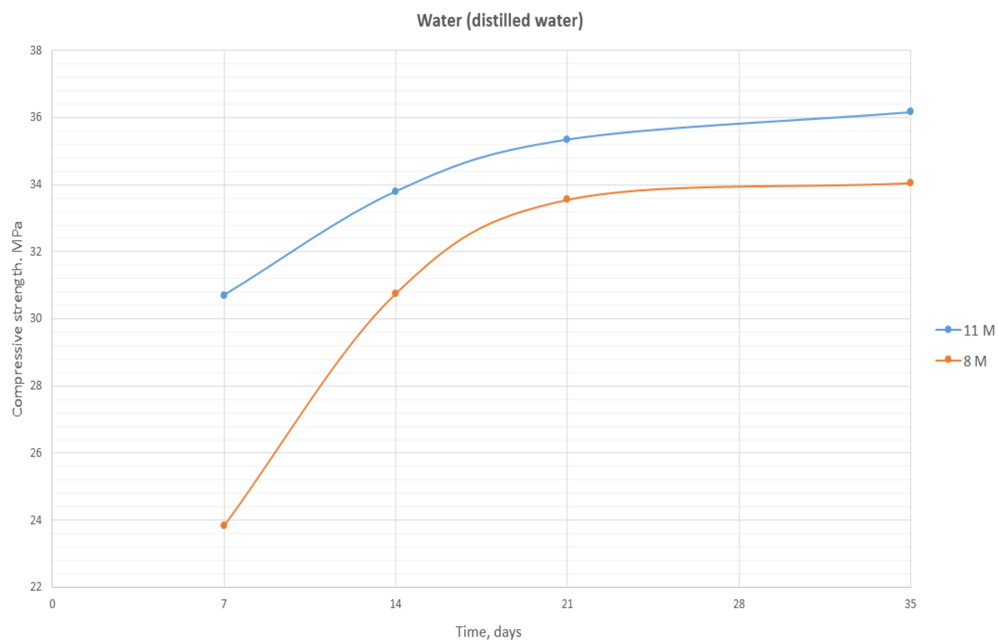


Figure 13: Strength comparison in normal water

Based on the result shown, the specimens immersed in distilled water have an increasing compressive strength but the specimens exposed to acid and salt have increasing strength on 14 days, and start to decrease at 21 days. This is because the effect of acid and chloride attack to the specimens. The specimens with 11M NaOH have a higher strength than 8M specimens. The concentration of NaOH in geopolymer mortar affect the strength of concrete. From this result, it can be concluded that the higher concentration of NaOH give a higher compressive strength.

4.3 Regression Data

The relationship between durability and compressive strength of geopolymer concrete shows by the coloration of both data. Those data will be inserted in excel to establish an equation on both parameter. The coloration of durability and strength is showed on figure below.

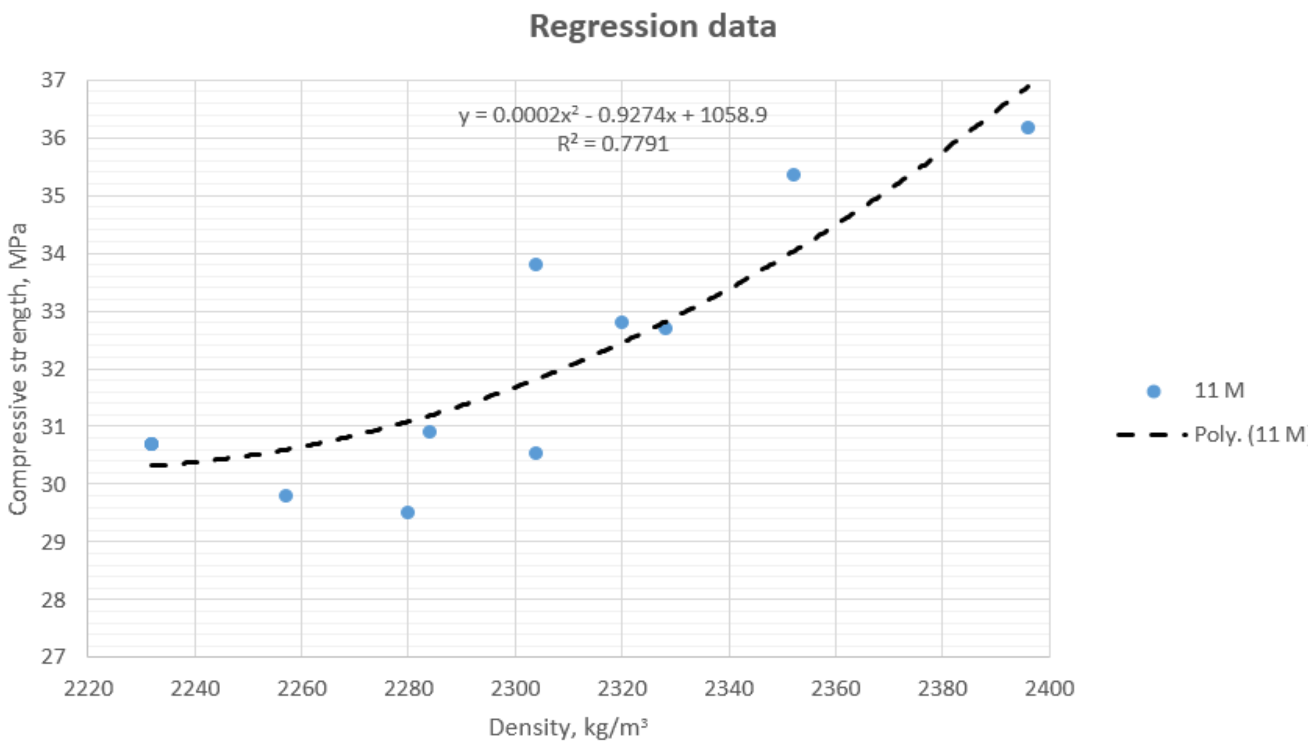


Figure 14: Regression data

The regression data of strength and density showed a uniform polynomial line as the density increase, the compressive strength also increase. This is because when the density is higher, the attack of acid and salt is lower because the decalcification in concrete happened very slow unless the concrete have low density. Thus, the strength also increase as decalcification is low. Hence, the establish equation produced by regression data is $y = 0.0002x^2 - 0.9274x + 1058.9$.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Relevancy to the Objective

In conclusion, the objectives of this project to analyze the behavior of geopolymer concrete in aggressive environment in term of durability and strength. Geopolymer concrete will be cured in three different exposures which is sulphuric acid, sodium chloride, and distilled water. As fly ash-based geopolymer concrete is rich in silica-alumina source, the experiment is relevant because it has excellent resistance to acid and chloride attack.

5.2 Suggested Future Work for Expansion and Continuation

There are a lot of factors affecting the strength and workability of geopolymer concrete. As the geopolymer concrete does not have its own standard for mix design, it is recommended for future work to continue the project as follows:

- Change the mix proportion of sand, fly ash, sodium hydroxide, and sodium silicate mix design.
- Have variation of sodium hydroxide molarity.
- Have variation ratio of sodium hydroxide and sodium silicate.
- Curing temperature can be varying in order to find optimum temperature.
- Adding an additive to increase the workability and strength of geopolymer concrete.

REFERENCES

1) Amir (2016). The Mechanical and Durability Properties of Geopolymer Concrete Using Sidoarjo Mud. Universiti Teknologi PETRONAS.

2) Ilyas Nurhadi (2015). Fly Ash Geopolymer concrete for Marine Structure Application. Universiti Teknologi PETRONAS.

3) Michael Terefe Woldemariam (2014). Effect of Ordinary Portland Cement in Geopolymer System. Universiti Teknologi PETRONAS.

4) Shankar H. Sanni & Khadiranaikar, R.B (2012). Performance of Geopolymer Concrete Under Severe Environmental Conditions, vol. 3, pp. 396-407. Basaveshwar Engineering College, Bagalkot, India.

5) Van Jaarsveld et al (1997). Literature Review on Geopolymer, retrieved from http://shodhganga.inflibnet.ac.in/bitstream/10603/22849/7/07_chapter2.pdf

6) K. Chinnasubbarao & G. Shani Priyanka (2015). Efeect of Aggressive Chemical Environment on Fly Ash based Geopolymer Concrete, volume 2, Issue 12, pp. 947-952. Priyadarshini Institute of Technology & Management.

7) D.V. Reddy, J-b Edouard, K. Sobhan & S.S. Rajpathak (2011). Durability of Reinforced Fly Ash-Based Geopolymer Concrete in the Marine Environment. Florida Atlantic University, USA.

8) S. Kumaravel & K. Girija (2013). Acid and Salt Resistance of Geopolymer Concrete with varying concentration of NaOH. Annamalai University, Annamalainagar-608 002, Tamilnadu, India.

9) Mr. K. Madhan Gopal & Mr. B. Naga Kiran (2013). Investigation on Behavior of Fly Ash Based Geopolymer Concrete in Acidic Environment, Vol 3, Issue 1, pp. 580-586. RGMCET, Nandyal, India.

10) Srinivas K S, M T Prathap Kumar, & W P Prema Kumar (2015). Comperative Performance of Geopolymer Concrete Exposed to Acidic Environment, Volume 4, Issue 4, pp. 27-31. Reva Institute of Technology and Management, Bengaluru, Karnataka, India.

11) S. E. Wallah and B. V. Rangan (2006). Low-Calcium Fly Ash-Based Geopolymer Concrete: Long-Term Properties. Faculty of Engineering Curtin University of Technology Perth, Australia.

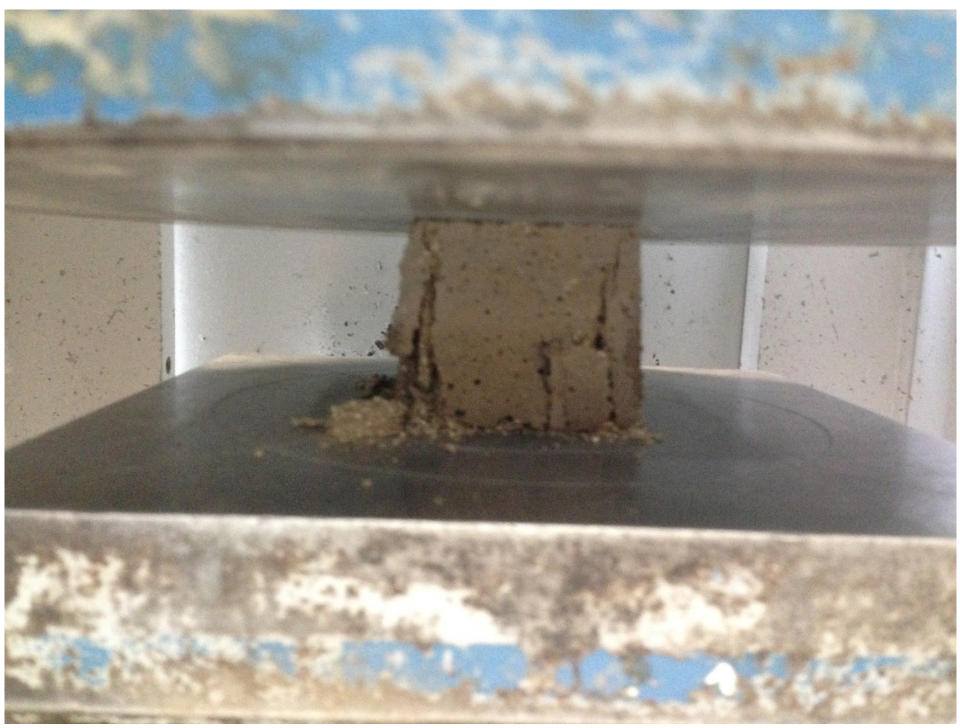
12) Xu, H. (2002). Geopolymerization of Aluminosilicate Minerals. Melbourne: University of Melbourne

APPENDICES

Appendix 1: Raw material

Appendix 2: Geopolymer mortar after cured in oven

Appendix 3: Specimens after cured in 3 different exposure



Appendix 4: Geopolymer mortar during compressive test