# SIDOARJO MUD AS A CEMENTITIOUS MATERIAL: A MYTH OR REALITY

By

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Supervisor: Associate Professor Ir Dr Hj Muhd Fadhil Nuruddin

Dissertation report submitted in partial fulfillment of
the requirement for the
BACHELOR OF ENGINEERING (Hons)
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Approved by,

____________________

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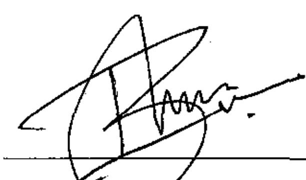
JULY 2008

## 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.



MARIADAS BRIAN MASILAMANI

# ABSTRACT

Since the production of Ordinary Portland Cement (OPC), an essential constituent of concrete, leads to the release of significant amount of $CO_2$, it has created some greenhouse effects. Many researches have been carried out to replace partially this OPC such as using Rice Husk Ash (RHA), Silica Fume, Lime Pozzolan, Fly Ash and many more. All this research shows and gives good result on concrete properties. Volcanic ash is believed to have some cementitious properties that can replace OPC. Volcanic eruption and earthquake is known as a major problem in Indonesia and in Jawa Timur (East Jawa) there is new type of catastrophe has been discovered known as Sidoarjo Hot Mud. This abundant nature waste is used as a research item to find its effect as cementitious material. The main objective of the study is to find the oxide and amorphous content in this mud (cementitious component) and use this mud to improve the quality of the concrete. The scope of study comprises of research on this mud as cement replacement material using XRD and XRF equipment. Several tests were carried out to find the compression and tensile strength. Porosity and Ultrasonic Pulse Velocity (UPV) tests were also employed to determine the effect of this mud. The tests were carried out with mixture ratio of 0, 5, 10, 15 and 20% of Sidoarjo mud and OPC to find the optimum ratio. The result showed that the mud can be used as cementitious material with optimum ratio of 10% Sidoarjo mud. It was found that Sidoarjo mud mortar achieved 30% of higher strength compared to OPC mortar. It was also noticed that the porosity level decrease 7% compare to control specimen. In term of tensile, and UPV tests Sidoarjo mud mortar showed 9% and 3% increases compare to OPC mortar respectively.

**ACKNOWLEDGEMENT**

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Improvement of concrete durability and strength are of the great concern, especially when the concrete is exposed to an aggressive environment. A large amount of research has been carried out to study both the durability and strength of concrete to obtain high performance concrete. The basic aspects of the production of high strength concrete are the use of supplementary cementing material. Due to growing environmental concerns and the need to conserve energy and resources, considerable efforts have been made worldwide to utilize local natural waste.

To produce an extremely good great concrete it should have more strength, good compressibility, impermeability and resistibility. The aim of the study is to use Sidoarjo mud known as hot mud from Jawa Timur Indonesia as a supplementary cementitious material for concrete and also as a supporting material to produce high grade bricks.

## 1.2 Problem Statement

Sidoarjo hot mud is one of the catastrophes that do happen in Jawa Timur and many life and material have lost for the pass few years. By early September 2006, area of approximately 240ha has been inundated by this mud flow. Beside that, more than 11,000 people have been affected and 2,983 people have been relocated to safer place. On November 2006, 11 fatalities were reported and the Marine and Fisheries Department has estimated financial loss of US$ 1.2 million to the fisheries business in this area.

The study is to check whether this mud can be used a cementitious material for concrete and increase the durability, compressibility and resistibility of the concrete. Current practice to increase the strength of concrete is to use cement replacement material such as fly ash, foundry sand, bottom ash, lime pozzolan and many more.

This material is proven to increase the strength, durability and impermeability of concrete.

Sidoarjo mud is believed to achieve all the criteria that cement should have such as the oxide and amorphous content which can be determined by using XRF and XRD test.

## 1.3 Objectives

Upon completing the project, a few objectives need to be achieved. The objectives are as below:

- To identify the oxide and amorphous content of Sidoarjo.
- To establish whether the mud have cementitious properties.
- To establish the effect of Sidoarjo mud into mortar.
- To identify the optimum level of Sidoarjo mud.

## 1.4 Scope of Study

The scope of study comprises of determination of oxide and amorphous content of Sidoarjo mud which has been defined as waste material, abundant and giving problem to the environment as well as human kind. This mud is from place called Sidoarjo which is situated in East Jawa, Indonesia. It has been confirmed that the mud flow has been trigged by the petroleum exploration in surrounding area.

The amorphousness and oxide contents of the mud are determined by using X-Ray Diffraction (XRD) and X-Ray fluorescence (XRF) test respectively. The dry sample of mud was used to mix mortar (OPC + H2o + Sidoarjo) and cast in 50 x 50mm cube mold and 100 x 200mm cylindrical type mold. The contents of the mud taken at 5, 10, 15 and 20% and the samples are tested at age 3, 7, and 28 days. The 0% sample is used as control specimen. The samples are tested using compression machine to test the compressive and tensile strength. Porosity and UPV of the sample are also determined.

# CHAPTER 2

# LITERATURE REVIEW AND THEORY

## 2.1 Concrete

Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel limestone or granite, plus a fine aggregate such as sand and water) and chemical admixtures. The word concrete comes from the Latin word "concretus", which means "hardened" or "hard" [1].

Concrete is a mixture of a binding agent (generally cement) to bond the other materials together: fine aggregate (sand), coarse aggregate (gravel/stones), and water. A typical composition is about 7-15% cement, 14-21% water and the rest aggregate. The water/cement ratio (w/c) of the mixture has a control over the final properties of the concrete. The water/cement ratio is the relative weight of the water to the cement in the mixture. The water/cement ratio is a factor selected by the civil engineer. Selection of a w/c ratio gives the engineer control over two desirable properties: strength and workability. A mixture with a high w/c will be more workable than a mixture with a low w/c: it will flow easier. But the less workable the mixture, the stronger the concrete will be. The civil engineer must decide what ratio will give the best result for the given situation. The water/cement ratio needs to be about 0.25 to complete the hydration reaction. Typical values of w/c are between 0.35 and 0.40 because they give a good amount of workability without sacrificing a lot of strength [1].

More concrete is used than any other man-made material in the world. As of 2006, about seven billion cubic meters of concrete are made each year—more than one cubic meter for every person on Earth. Concrete powers a US$35-billion industry which employs more than two million workers in the United States alone. More than 55,000 miles of highways in America are paved with this material. The People's

Republic of China currently consumes 40% of the world's cement [concrete] production. Concrete is used to make pavements, architectural structures, foundations, motorways/roads, bridges/overpasses, parking structures, brick/block walls and footings for gates, fences and poles. All this information shows that concrete is important material for our daily life. In spite of that lot of concrete replacement material has been produce to strengthen the concrete or to produce a replacement for cement [2].

### 2.1.1 Hydration Process

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. The reactions are highly exothermic and care must be taken that the build-up in heat does not affect the integrity of the structure.

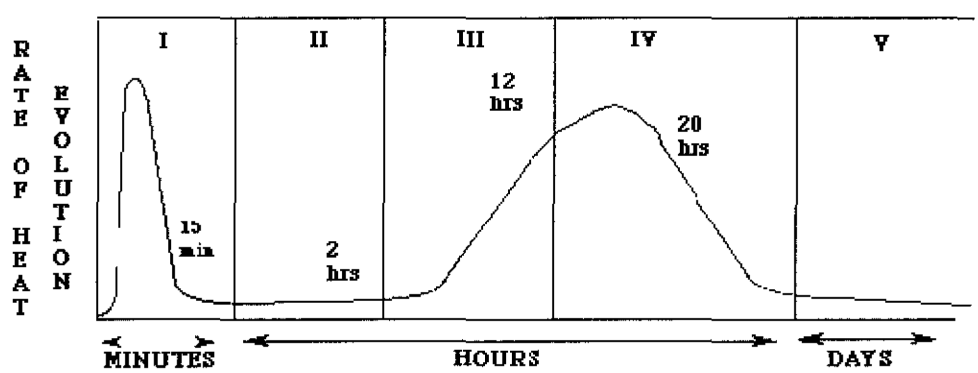


**Figure 2.1:** Rate of heat evolution during the hydration of portland cement

Figure 2.1 explained the rate of heat evolution during hydration process. The stage I hydrolysis of the cement compounds occurs rapidly with a temperature increase of several degrees. Stage II is known as the dormancy period. The evolution of heat slows dramatically in this stage. The dormancy period can last from one to three hours. During this period, the concrete is in a plastic state which allows the concrete to be transported and placed without any major difficulty. This is particularly important for the construction trade who must transport concrete to the job site. It is at the end of this stage that initial setting begins. In stages III and IV, the concrete starts to harden and the heat evolution increases due primarily to the hydration of tricalcium silicate. Stage V is reached after 36 hours. The slow formation of hydrate products occurs and continues as long as water and unhydrated silicates are present [3].

### 2.1.2 Cement Hydration Products

The products of the reaction between cement and water are termed 'hydration products.' In concrete (or mortar or other cementitious materials) made using Portland cement only as the cementitious material there are four main types of hydration product [5]:

**Calcium silicate hydrate:** this is the main hydration product and is the main source of concrete strength. It is often abbreviated; using cement chemists' notation, to 'C-S-H,' the dashes indicating that no strict ratio of $SiO_2$ to CaO is inferred. The Si/Ca ratio is somewhat variable but typically approximately 0.45-0.50.

**Calcium hydroxide** - $Ca(OH)_2$: often abbreviated, using cement chemists' notation, to 'CH.' CH is formed mainly from alite hydration. Alite has a Ca:Si ratio of 3:1 and C-S-H has a Ca/Si ratio of approximately 2:1, so excess lime is available from alite hydration and this produces CH.

**Ettringite:** ettringite is present as rod-like crystals in the early stages of cement hydration. The chemical formula for ettringite is $[Ca_3Al(OH)_{6.12H2O}]_{2.2H2O}$ or, mixing cement notation and normal chemistry notation, $C_3A.3CaSO_4.32H_2O$.

**Monosulfate:** monosulfate tends to occur in the later stages of hydration, after a few days. Usually, it replaces ettringite, either fully or partly. The chemical formula for monosulfate is $C_3A.CaSO_4.12H_2O$. Both ettringite and monosulfate are compounds of $C_3A$, $CaSO_4$ (anhydrite) and water, in different proportions.

**Hydrogarnet:** hydrogarnet forms mainly as the result of ferrite or $C_3A$ hydration. Hydrogarnets have a range of compositions, of which $C_3AH_6$ is the main phase forming from normal cement hydration and then only in small amounts. A wider range of hydrogarnet compositions can be found in autoclaved cement products.

### 2.1.3 Types of Concrete

There are many type of concrete depend on the usage and the mixture ratio. Table 2.1 explained the types of concrete [5].

**Table 2.1:** Types of concrete

| Type of Concrete | Description |
|---|---|
| Cement concrete | This is the most common type of concrete and is made mostly from portland cement, sand, aggregate and water. It is used reinforce and un-reinforce for structures, roads, foundational. The compositions of cement, sand and aggregate vary from 1:1:2 ( a richest practical mixture) to 1:3 :6 (a lean mixture used for concrete filling) |
| Plain mass concrete | Concrete not strengthened by reinforcement. Used for foundations and mass structures such as damn, and gravity retaining walls. also called non-reinforced concrete |
| Lean concrete | A plain concrete with a large ratio aggregate to cement than structural concrete. It is used for filling and not structural duties |
| Structural concrete | Lightweight concrete of such a quality that it is suitable for load-bearing members of structures. If it is a compact concrete made with stone aggregate, it is of comparatively high density (about 2.4) and great strength. If it is based on lightweight aggregate then high strengths are available but the design generally requires special considerations |
| Reinforced concrete | Lightweight concrete of such a quality that it is suitable for load-bearing members of structures. If it is a compact concrete made with stone aggregate, it is of comparatively high density (about 2.4) and great strength. If it is based on lightweight aggregate then high strengths are available but the design generally requires special considerations |
| Prestressed concrete | Structural concrete which is subjected to compression in those parts which in service are subjected to tensile forces so that generally, the concrete is nowhere is a state of tension under the working load. |
| Cast in Place /Cast in Situ Concrete | This is deposited in its permanent position to harden. This is the most common method of construction and when to concrete is not deposited on the ground as for roads and similar it is generally placed in temporary moulds or is contained within formwork or shuttering. |
| Precast Concrete | This is concrete which placed in separate moulds, under controlled factory conditions, to harden and when required transferred to site for final erection. This procedure allows high quality concrete castings to be made at low relative costs. This method is used for the production of paving slabs, bricks, road channels, kerbs lintels, fence posts, bridge beams etc. Precast units can include re-inforcement and Engineered steel inserts. |

## 2.2 Pozzolan

A pozzolan is a material which, when combined with calcium hydroxide, exhibits cementitious properties. Pozzolans are commonly used as an addition (the technical term is "admixture") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete. Pozzolans are primarily vitreous siliceous materials which react with calcium hydroxide to form calcium silicates; other cementitious materials may also be formed depending on the constituents of the pozzolan [6].

The first known pozzolan was pozzolana, a volcanic ash, for which the category of materials was named. The most commonly used pozzolan today is fly ash, though silica fume, high-reactivity metakaolin, ground granulated blast furnace slag, and other materials are also used as pozzolans. RHA is a by product of paddy that can be obtained with the combustion process of rice husk. The high content of amorphous silica and very large surface area make RHA become a highly reactive pozzolanic material that can be used to improve the strength and durability of concrete. Generally, reactivity of pozzolanic material can be achieved by increasing the fineness degree of the material. However, Mehta has argued that grinding of RHA to a high degree of fineness should be avoided, since it derives its pozzolanic activity mainly from the internal surface area of the particles. At a certain stage of grinding the RHA, the porous structure of the particle will collapse, thereby reducing the surface area of the RHA [6].

In other case finely ground lime-pozzolan binder (LPB) is also used as concrete replacement material. The very fine lime particles, having size between 0.1and 10 μm, can fill the gaps between OPC grains, while the larger pozzolan particles, having size between 10 and 100 μm, can fill the gaps between fine aggregate grains. The result is a much denser matrix. The addition of lime [$Ca(OH)_2$] during concrete mixing also increases the $Ca^{2+}$ and $OH^-$ ion concentrations, which results in a better and faster hydration of both OPC and pozzolans. The use of LPB as an active addition in some concretes could contribute to lowered product cost with equivalent strength and durability performance through the use of less cement. Thus, the ecologic profile of the material is improved [6].

### 2.2.1 Natural Pozzolan

Pozzolans are present on earth's surface such as diatomaceous earth, volcanic ash, opaline shale, pumicite, and tuff. Figure 2.2 is a porous pozzolan which is used as lightweight aggregates. These materials require further processing such as calcining, grinding, drying, etc. The Aegean island of Santorini has natural deposits of volcanic ash (Santorin earth.) In the United States, volcanic tuffs and pumicites, diatomaceous earth, and opaline shales are found principally west of the Mississippi River in Oklahoma, Nevada, Arizona, and California. Natural pozzolans have been used in dams and bridges to lower the heat of hydration and increase resistance of concrete to sulfate attack and control the alkali-silica reaction. Usually the pozzolanic deposit must be in the vicinity of the project to support mining and processing costs [7].

**Figure 2.2:** Natural porous pozzolan as lightweight aggregates

### 2.2.2 Artificial Pozzolan

Fly ash is an artificial pozzolan produced when pulverized coal is burned in electric power plants. The glassy (amorphous) spherical particulates are the active pozzolanic portion of fly ash. Fly ash is 66-68% glass. Class F fly ash (see ASTM C 618) readily reacts with lime (produced when portland cement hydrates) and alkalies to form cementitious compounds. Class C fly ash also may exhibit hydraulic (self-cementing) properties. Hungry Horse, Canyon Ferry, Palisades, Yellowtail dams all contains portland cement-fly ash concrete. Fly ash under SEM test is shown in figure 2.3 [7].

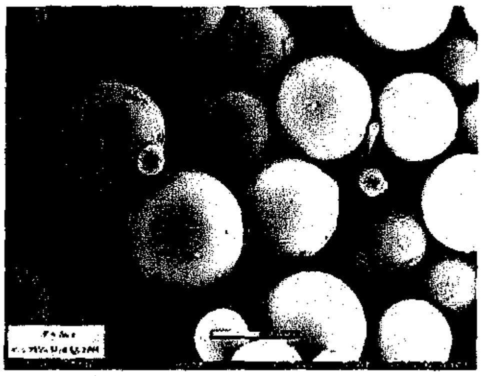

**Figure 2.3:** Fly ash under SEM

### 2.2.3 Criteria of Pozzolan

A pozzolan is a siliceous or aluminosiliceous material, which is highly vitreous. This material independently has few/fewer cementitious properties, but in the presence of a lime-rich medium like calcium hydroxide, shows better cementitious properties towards the later day strength (> 28 days).The mechanism for this display of strength is the reaction of silicates with lime to form secondary cementitious phases (calcium silicate hydrates with a lower C/S ratio) which display gradual strengthening properties usually after 7 days.

### 2.2.4 Pozzolanic Reaction

The pozzolanic reaction may be slower than the rest of the reactions that occur during cement hydration, and thus the short-term strength of concrete made with pozzolans may not be as high as concrete made with purely cementitious materials. On the other hand, highly reactive pozzolans, such as silica fume and high reactivity metakaolin can produce "high early strength" concrete that increases the rate at which concrete gains strength [11].

The extent of the strength development depends upon the chemical composition of the pozzolan: the greater the composition of alumina and silica along with the vitreous phase in the material, the better the pozzolanic reaction and strength display [11].

### 2.2.5 Effect of Pozzolan

The effect of pozzolan material varies; depend on what type of material is used. The effect of a natural pozzolan on the strength of concrete varies markedly with the properties of the particular pozzolan and with the characteristics of the concrete mixture in which is used. The strength development is a function of the chemical interaction between the natural pozzolan and the Portland cement during hydration. Nevertheless, many engineers still have limited knowledge of the way in which pozzolan influences the properties of concrete. Therefore, it is desirable to investigate the properties and behavior of each type of available pozzolan concrete more comprehensively [12].

A pozzolan requires the presence of a reactive alumino-silicate glass. These glassy particulates must be fine enough to provide a sufficient reactive surface area for the solid-state chemical reactions. This reactive glass reacts with available calcium hydroxide and alkalies to produce cementitious compounds. (Calcium-silicate hydrates gel and calcium-alumino silicates, etc) [12].

## 2.3 Sidoarjo Mud

Since May 2006, more than 10,000 people in the Porong sub district have been displaced by the hot mud flowing from a natural gas well being drilled by Lapindo Brantas, an oil well company that is part of a conglomerate owned by Coordinating Minister for the People's Welfare Aburizal Bakrie. The mud flow is shown in figure 2.4 which has been taken from NASA satellite map. Gas and hot mud starting spewing from the well on May 28, when the drill penetrated a layer of liquid sediment. Attempts to pump concrete down the well did not stop the flow. While some scientists have speculated that the earthquake that struck Yogyakarta on May 27, the day before the well erupted, may have cracked the ground, creating potential pathways for the mud to reach the surface, others have suggested that the drilling procedure was faulty by not using a casing. Some 50,000 cubic meters of hot mud were erupting every day as of August; in September, the amount increased to some

125,000 cubic meters daily. On September 26 barriers built to hold back the mud failed, resulting in the flooding of more villages. As of late September 2006 scientists are saying that the eruption may be a mud volcano forming, and may be impossible to stop [17].

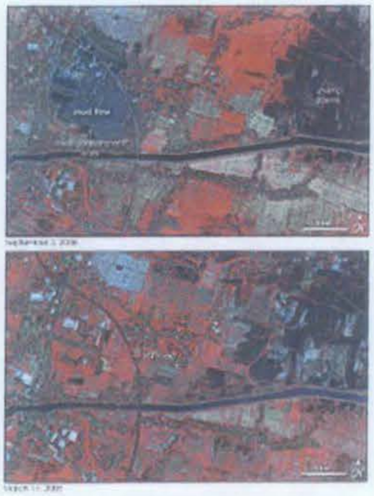

**Figure 2.4:** NASA satellite maps of the area before (lower picture) and after (upper picture) the mud flow

### 2.3.1 Impact of the mud flow

The impact of this mud is devastating. By early September 2006 a hot torrential mudflow had inundated rice paddies and villages, covering an area of approximately 240 ha and resulting in the displacement of more than 11,000 people from eight villages in the Porong subdistrict. Twenty-five factories had to be abandoned, rice fields and fish and shrimp ponds were destroyed, which further threatened Sidoarjo's status as the biggest shrimp producer in Indonesia after Lampung. The Marine Resources and Fisheries Ministry has estimated a financial loss of 10.9 billion rupiahs (US$ 1.2 million) to the fisheries business in Tanggulangin and Porong subdistricts. President Susilo Bambang Yudhoyono declared the 400 ha area inundated by the mud flow as a disaster-prone area unfit for human habitation. As a consequence, 2,983 families had to be relocated to safer places [17].

On 23 November 2006, eleven fatalities were reported from the explosion of a gas pipe caused by the mud flow. The accident occurred due to significant subsidence of the ground, up to 2 m (6.5 ft), due to the outflow of mud causing a dyke to collapse resulting in the rupture of the state-owned Pertamina gas pipeline. The gas sent flames into the sky and according to the local people; the heat could be felt one kilometer (0.6 miles) away [17].

As of December 2007 the total volume of expelled mud was estimated at 1 billion cubic feet, covering an area of 2.5 square miles, burying eleven towns and displacing at least 16,000 people. It is expected that the mud eruption will last for years to come and the area will experience a significant depression, forming a large caldera. Transportation and power transmission infrastructure has been damaged extensively in the area. Speaking in front of the People's Representative Council, the house speaker Agung Laksono declared that the state will need to finance the infrastructure repairs, while PT Lapindo Brantas will be responsible for financing the ongoing mitigation effort and also to pay 2.5 trillion rupiah as compensation to the victims. The Porong-Gempol toll road in East Java province has been significantly damaged by the mud flow and is practically inoperable [17].

**Figure 2.5:** Current situation in effected area

### 2.3.2 Mitigation

A network of dams and barriers has been erected to contain the mud. In September 2007, 26 barriers failed resulting in the flooding of more villages. Further strengthening of the dam system appears to contain the sludge and since the end of

September no further reports of breaches have been released. The displaced population has been given temporary shelter. President Susilo Bambang Yudhoyono has authorized further flow of mud to be pumped into the Porong River that will take it to the local sea. Pumping of sludge into the sea started on 16 October 2007. Ideas have been submitted for the use of the mud, as it could be used for bricks and other building material. The heat of the process may be usable for thermal energy. There has also been an effort to stop and/or lessen the effects of the mud flow through the dropping of chains of concrete balls into the crater. The hope is to shrink the size of the evacuation tube and thus slow the rate of flow [17].

Drilling operations have been seriously hampered, with continual delays forced upon the relief well drilling team, due to lack of funding. Drilling operations have been suspended until the implementation of the National Government Team's plan to plug the flow with concrete "balls", a plan widely accepted to offer more inherent dangers than chances of success (and potentially induce further flows to the surface in an area already severely weakened). The first series of concrete balls was lowered into the mud volcano on 24th February 2007. It is planned that up to 1500 such balls will be deployed. On 19th March 2007, after hundreds of balls had been dropped into the mouth of the hole, the flow of mud stopped for a period of 30 minutes [17].

## 2.4 Sidoarjo Mud as Cement Replacement Material

There are lot of cement replacement material such as silica fume RHA, fly ash and many more. Sidoarjo mud is believed to have cementitious properties that content oxides such as CaO, $SiO_2$. MgO etc which are similar to other pozzolan. This can be proved by the XRF and XRD test. Most of the Earth's crust consists of oxides, this give a first idea that the mud can content oxide.

### 2.4.1 X-Ray Diffraction test (XRD)

XRD test is used to measure mineral abundances in rocks and material such as salts and scale samples. XRD analysis is typically carried out on both bulk rock and clay fraction samples. The diffraction of X-rays produced by the atom within crystal, used to determine the information about the crystal's structure.

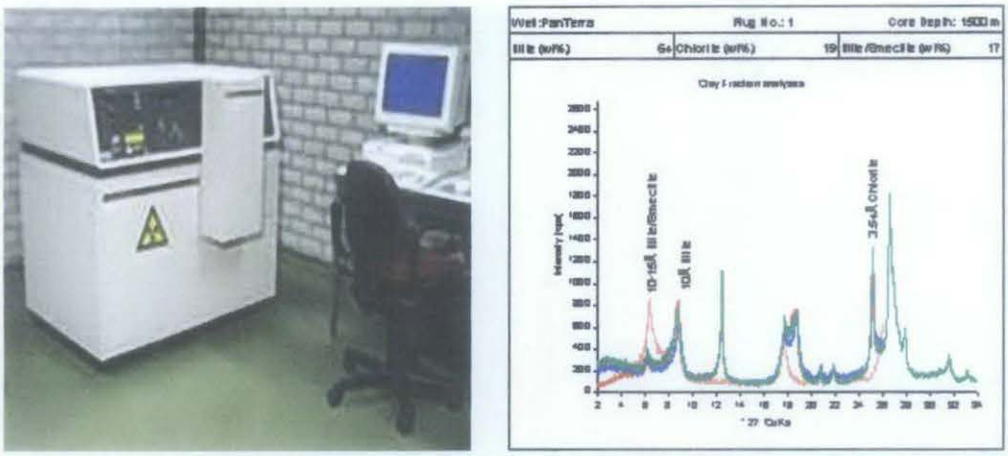

**Figure 2.6:** XRD testing machine and possible outcome of results

### 2.4.2 X-Ray Fluorescence test (XRF)

XRF is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry, forensic science and archeology. Figure 2.7 shows the machine and the possible outcome of the result.

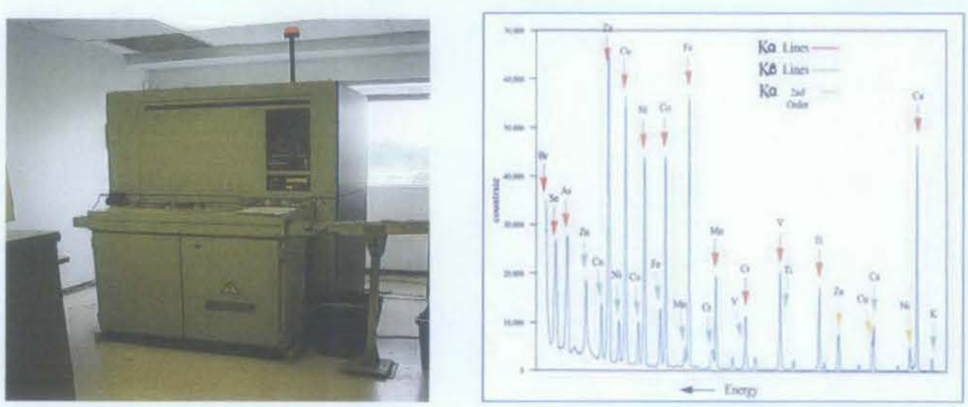


**Figure 2.7:** XRF testing machine and possible outcome of results

### 2.4.3 Scanning Electron Microscope test (SEM)

Ultra-small structures encompass a range of structure sizes sometimes described as micro- or nano-sized. Objects with dimensions measured in ones, tens or hundreds of microns are described as micro-sized. Objects with dimensions measured in ones, tens or hundreds of nanometers or less are commonly designated nano-sized. Ultra-small hereinafter refers to structures and features ranging in size from hundreds of microns in size to ones of nanometers in size. This test is used to determine the structure of the mud which can be similar to cementitious material. Figure 2.8 shows the machine and the possible outcome of the result.

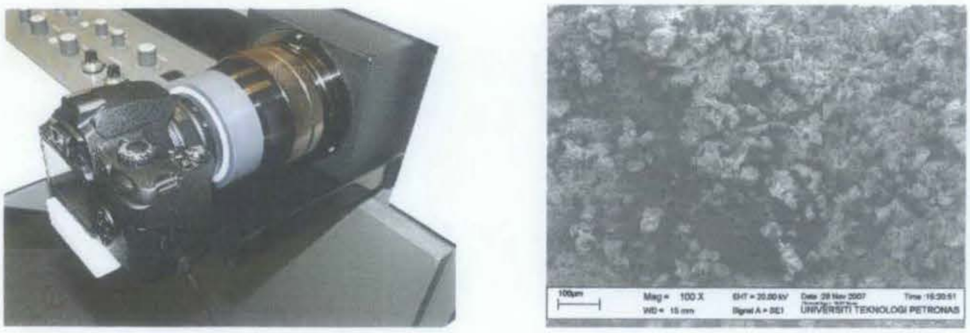


**Figure 2.8:** SEM testing machine and possible outcome of results

# CHAPTER 3

# METHOLODOGY

## 3.1 Project Flow

Figure 3.1 shows the flowchart of this project, which explained the flow of the project accordingly.

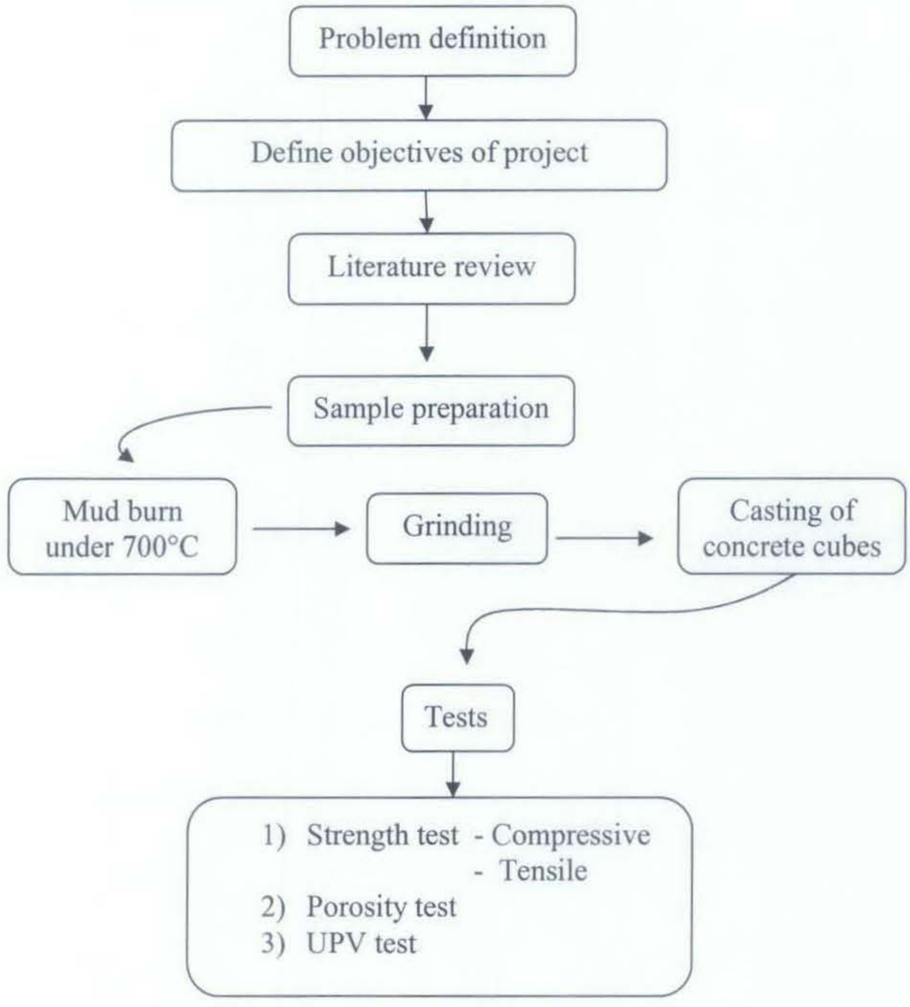


**Figure 3.1:** Process of project flow

## 3.2 Laboratory Equipment

Laboratory equipment refers to the various tools and equipment used while in a laboratory. Laboratory equipment is generally used to either perform an experiment or to take measurements and gather data. These include machines such as concrete mixing machine, furnace, compression machine and coring machine.

### 3.2.1 Furnace

A furnace is a device used for heating. Figure 3.2 is the picture of furnace which has been used for this experiment. In this project furnace is used to burn the mud under elevated temperature until it reaches 700°C. The purpose of heating is to burn out all the debris and unwanted material in the mud. Soon after the burning process is done the mud can be ground.

**Figure 3.2:** Furnace

### 3.2.2 Grinding Machine

A grinding machine is a machine tool used for producing very fine finishes or making very light cuts, using an abrasive wheel as the cutting device. The dry mud is then ground using 3 phase of 1000 rotation to make it fine as cement. This will help the mud react effectively with cement.

**Figure 3.3:** Grinding Machine

### 3.2.3 Concrete Mixer

A concrete mixer (also commonly called a cement mixer) is a device that homogeneously combines cement, aggregate such as sand or gravel, and water to form concrete. A typical concrete mixer uses a revolving drum to mix the components. In this project the cement, sand and the mud is mix together to form a mortar which will than use to test the concrete properties such as strengths and porosity. Figure 3.4 is the mixing machine which is used to mix Sidoarjo mud mortar.

**Figure 3.4:** Concrete Mixer

### 3.2.4 Compression Testing Machine

The 3, 7 and 28days cured mortar are tested using 3000kN compression testing machine as shown in figure 3.5. This machine is calibrated using BS 1881 to find the compressive and tensile strength of the mortar. By using this machine the stress and the maximum load were determined. The pace of the compression is 0.9mm$^2$ for compressive strength and 0.93mm$^2$ for tensile strength.


**Figure 3.5:** Compression testing machine

### 3.2.5 Coring Machine

Figure 3.6 machine is used to core 3 numbers of 1" x 2" cylindrical type samples for each mixture which were used for porosity test. The coring is done using BS 1881 and the cored samples are cured for 28days.

**Figure 3.6:** Coring machine

## 3.3 Experimental Details

This project comprises of 4 major test which are compressive and tensile strength, porosity and UPV test. The test is carried out for five (5) different mixture ratios 0, 5, 10, 15, and 20% content of Sidoarjo mud. Water cement (w/c) ratio taken as 0.5 and sand cement (s/c) ratio taken as 1. Table 3.1 shows the calculation of the mixture.

**Table 3.1:** Calculation of mixtures

| Mix | Mud (%) | Cement (kg/m$^3$) | Sand (kg/m$^3$) | Water (kg/m$^3$) | Mud (kg/m$^3$) |
|---|---|---|---|---|---|
| 1 | 0 | 841.74 | 841.74 | 420.87 | 0.00 |
| 2 | 5 | 799.66 | 799.66 | 399.83 | 42.09 |
| 3 | 10 | 757.57 | 757.57 | 378.78 | 84.17 |
| 4 | 15 | 715.48 | 715.48 | 357.74 | 126.26 |
| 5 | 20 | 673.39 | 673.39 | 336.70 | 168.35 |

### 3.3.1 Compressive Strength

This test is carried out to find the compressive strength is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. 3 samples of 50 x 50 x 50mm concrete cube are used to determine the strength by taking the average value.

### 3.3.2 Tensile Strength

This test is carried out to find the tensile strength $\sigma_{UTS}$, or $S_U$ at which a material breaks or permanently deforms. 3 cylindrical type 100x 200mm samples are used to find the stress. Tensile strength is an intensive property and, consequently, does not depend on the size of the test specimen. However, it is dependent on the preparation of the specimen and the temperature of the test environment and material.

### 3.3.3 Porosity

Porosity is a measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100percent. This test used 3 cylindrical type samples 1" x 2". The sample were submerged is vacuum bowl for 6 hour. Later the saturated and water weight of sample were measured. Than the samples were dried for 24 hours and the dry weight were measured. If the amount of porosity is high the strength will decrease and if the amount of porosity is low the strength will increase.

### 3.3.4 UPV

This test has been carried out to find the integrity between the mixtures and also find the consistency of the mud into the increasing of concrete properties. 3 numbers of 50 x 50 x 50mm concrete cube samples are used. The pulse velocities are determined by the pundit machine which gave the transit time.

Table below gives brief description of the experiments which have been carried out during this project.

**Table 3.2:** Experimental details

| | Sample Description | | | | | | |
|---|---|---|---|---|---|---|---|
| **Test** | **Size (mm)** | **No** | **Age (days)** | **Standard** | **Unit** | **Measure** | **Equipment** |
| Strength | 50 x 50 x 50 | 3 | 3, 7, 28 | BS1881:Part 116:1983 | $N/mm^2$ or MPa | Compression | Compression testing machine 3000KN |
| Tensile | 100 x 200 | 3 | 28 | BS1881:Part 117:1983 | $N/mm^2$ or MPa | Split/ Tensile | Compression testing machine 3000KN |
| Porosity | 1" x 2" | 3 | 28 | BS1881:Part 124:1988 | % | Ratio of void or air spaces | Vacuum bowl and weighing machine |
| UPV | 50 x 50 x 50 | 3 | 28 | BS1881:Part 201:1986 | km/s | Integrity | UPV testing machine |

## 3.4 Constituent Materials

The individual material that make up a composite material. XRD and XRF test is used to find the constituent material of mud.

### 3.4.1 OPC

Ordinary Portland Cement (OPC) is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or groundwater. The quality requirements specified in the Malaysian Standard MS 522:Part1:1989 specifications for Ordinary Portland Cement. The OPC chemical reaction would be (OPC + $H_2O \longrightarrow Ca(OH)_2$).

### 3.4.2 Sidoarjo mud

The amounts of mud differ for each mixture, 5, 10, 15, and 20% content of mud for. The chemical reaction would be (pozzolan + $Ca(OH)_2 \longrightarrow$ CSH + CAH).

### 3.4.3 Sand

ISO 14688 grades sands as fine, medium and coarse with ranges 0.063 mm to 0.2 mm to 0.63 mm to 2.0 mm. In USA, sand is commonly divided into five subcategories based on size: very fine sand (1/16 - 1/8 mm diameter), fine sand (1/8 mm - 1/4 mm), medium sand (1/4 mm - 1/2 mm), coarse sand (1/2 mm - 1 mm), and very coarse sand (1 mm - 2 mm). The mortar mixture used medium sand (1/4 mm - 1/2 mm).

**Figure 3.7:** Close-up showing a surface area of (approximately) between 1-2 square centimeters.

### 3.4.4 Chemical composition and Oxide content of mud

To find the chemical composition, XRF test is applicable meanwhile for oxide content XRD test is used. The result of the test has been attached in the table and figure below.

**Table 3.3:** Chemical composition of mud

| Element | Weight % | Atomic % |
|---|---|---|
| O K | 67.17 | 96.25 |
| Na K | 2.88 | 2.87 |
| Mg K | 1.55 | 1.47 |
| Al K | 10.76 | 9.14 |
| Si K | 24.74 | 20.19 |
| S K | 0.71 | 0.51 |
| Cl K | 2.59 | 1.67 |
| K K | 1.21 | 0.71 |
| Ca K | 1.93 | 1.10 |
| Ti K | 0.49 | 0.24 |
| Fe K | 4.92 | 2.02 |

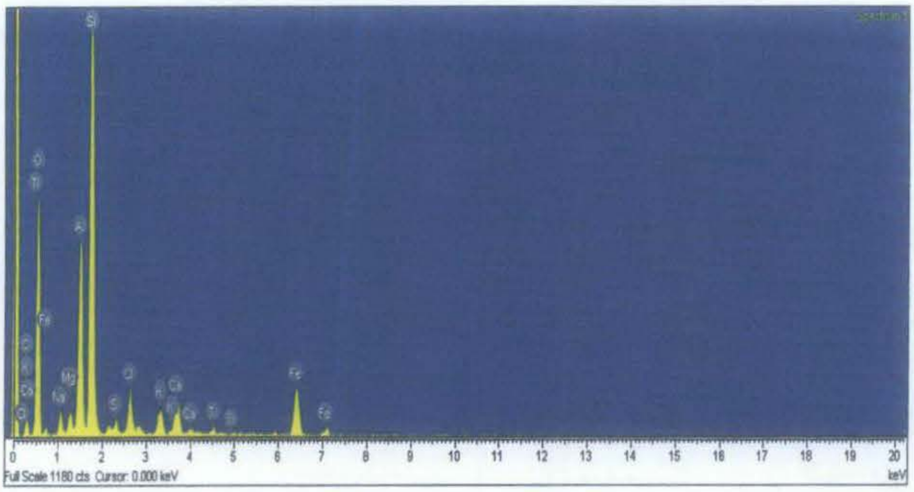


**Figure 3.8:** Chemical content of mud

**Table 3.4:** Comparison of oxide content

| Oxide | OPC (%) | SF (%) | MUD (%) |
|---|---|---|---|
| $Na_2O$ | 0.0164 | 0.1186 | 15.9504 |
| $MgO$ | 1.4334 | 0.5196 | 0.8357 |
| $Al_2O_3$ | 2.8357 | 0.21 | 12.8214 |
| $SiO_2$ | 20.4449 | 96.355 | 46.6714 |
| $P_2O_5$ | 0.1023 | 0.1287 | 0.2296 |
| $K_2O$ | 0.2646 | 1.0181 | 2.0042 |
| $CaO$ | 67.7341 | 0.2396 | 3.3055 |
| $TiO_2$ | 0.1701 | 0.0078 | 1.3322 |
| $Fe_2O_3$ | 4.6352 | 0.7701 | 15.5525 |
| $SO_3$ | 2.202 | 0.5504 | 1.0536 |
| $MnO$ | 0.1614 | 0.0819 | 0.2436 |

## 3.5 Process Flow of Sidoarjo mud

Before the mud is tested as cement replacement material (CRM) it should underwent several stages shown in the figure below.

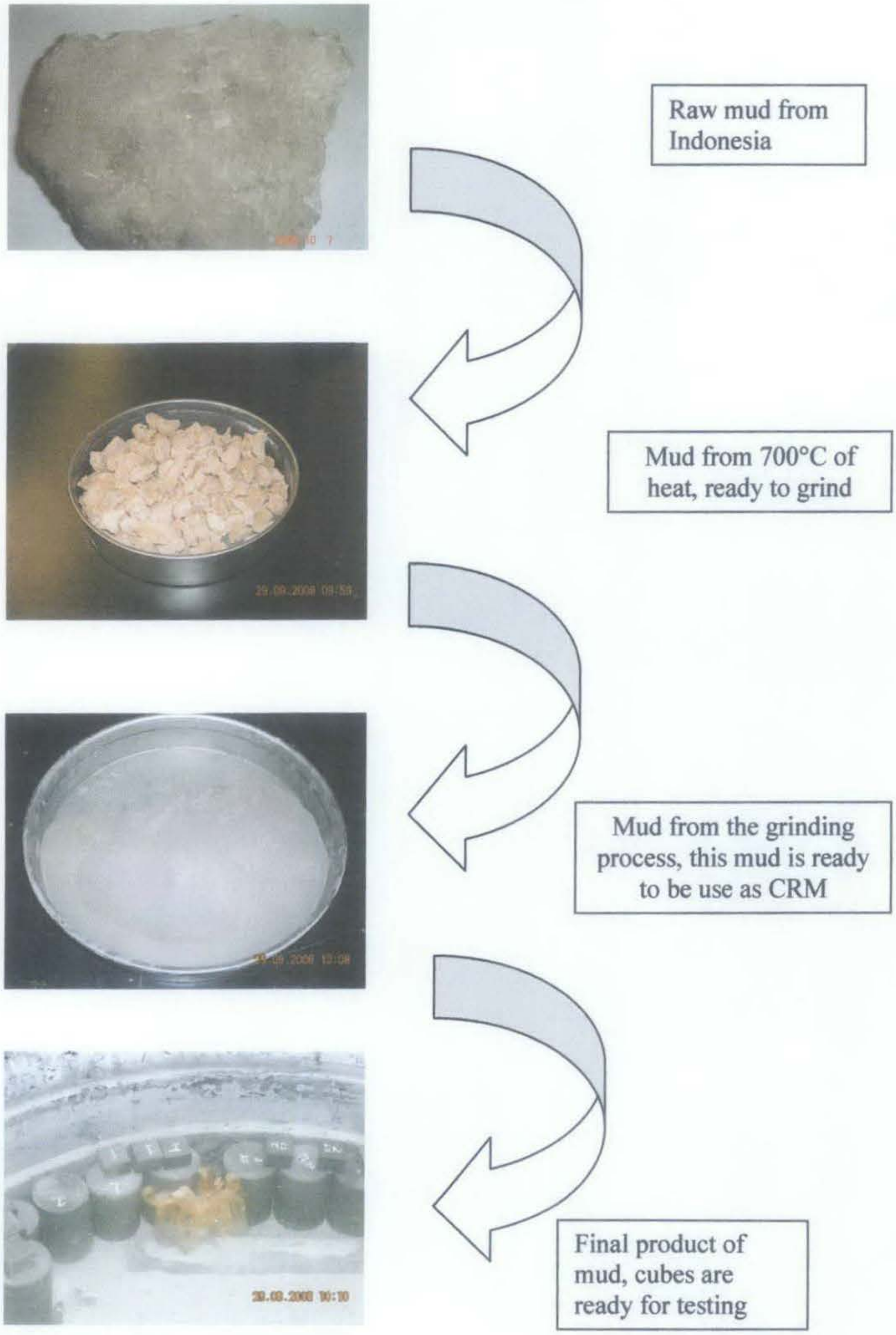


**Figure 3.9:** Process flow of Sidoarjo mud

## 3.6 Health Safety & Environment (HSE)

Through out this project, safety precaution has been given main priority. This is because to avoid any unnecessary incident or accident. A student should not have to risk injury at lab, nor should others associated with the work environment.

### 3.6.1 Activity

- Concrete mixing
- Testing concrete cubes under elevated temperatures (furnace)

### 3.6.2 Hazard

- *Staggered objects on the floor*

Equipments that are used by students are normally placed carelessly on the floor along the walking path of other students.

Example: concrete cubes, hammer, reinforcement bars, concrete moulds.

- *Sharp objects*

The area next to the concrete mixer has scattered nails and other broken objects. Beside that, concrete cubes which have failed under compression test have to be disposed at the designated area.

Example: damaged concrete cubes (compression test), nails, and shovel.

- *Machinery*

The lid of the concrete mixer has to be manually held down while being used due to problems with the lever.

Example: concrete mixer

- *Electricity*

The wire connecting the concrete mixer to the plug point hangs 0.4m above the ground this could trigged electric shock. Beside that, some students handle electrical equipments and plug points with out cleaning or drying their hands.

Example: wires, plug points, electrical equipment

### 3.6.3 Prevention

- *Staggered objects on the floor*

If possible, students should wear safety boots or shoes that completely cover the foot.

- *Sharp objects*

Always use protective gloves.

- *Machinery*

When handling heavy machinery, make sure not to work alone.

- *Electricity*

Do not operate electrical equipment and plug points with dirty or wet gloves.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Results

Experiment results for laboratory work are attached here along with its discussion. The results comprises of strength test, porosity test and UPV test.

### 4.1.1 Compressive Strength

The purpose of the experiment is to analyze the effect of mud into concrete in term of compressive strength.

**Table 4.1:** Result of compressive strength

| | | **(0%)**<br>Sample | | |
|---|---|---|---|---|
| Days | 1 | 2 | 3 | Stress(Mpa) |
| 3 | 19.53 | 24.2 | 23.24 | 22.32 |
| 7 | 31.39 | 34.94 | 32.09 | 32.81 |
| 28 | 48.29 | 42.95 | 47.49 | 46.24 |
| | | **(5%)** | | |
| 3 | 27.56 | 29.72 | 28.99 | 28.76 |
| 7 | 37.93 | 37.5 | 33.42 | 36.28 |
| 28 | 58.44 | 54.44 | 52.59 | 55.16 |
| | | **(10%)** | | |
| 3 | 32.08 | 30.06 | 31.24 | 31.13 |
| 7 | 40.77 | 41.64 | 43.01 | 41.81 |
| 28 | 61.8 | 58.96 | 53.05 | 57.94 |
| | | **(15%)** | | |
| 3 | 23.16 | 28.52 | 23.92 | 25.20 |
| 7 | 31.23 | 30.65 | 32.77 | 31.55 |
| 28 | 38.98 | 53.05 | 42.15 | 44.73 |
| | | **(20%)** | | |
| 3 | 21.38 | 23.86 | 23.55 | 22.93 |
| 7 | 32.8 | 29.68 | 31.15 | 31.21 |
| 28 | 32.78 | 32.06 | 43.06 | 35.97 |

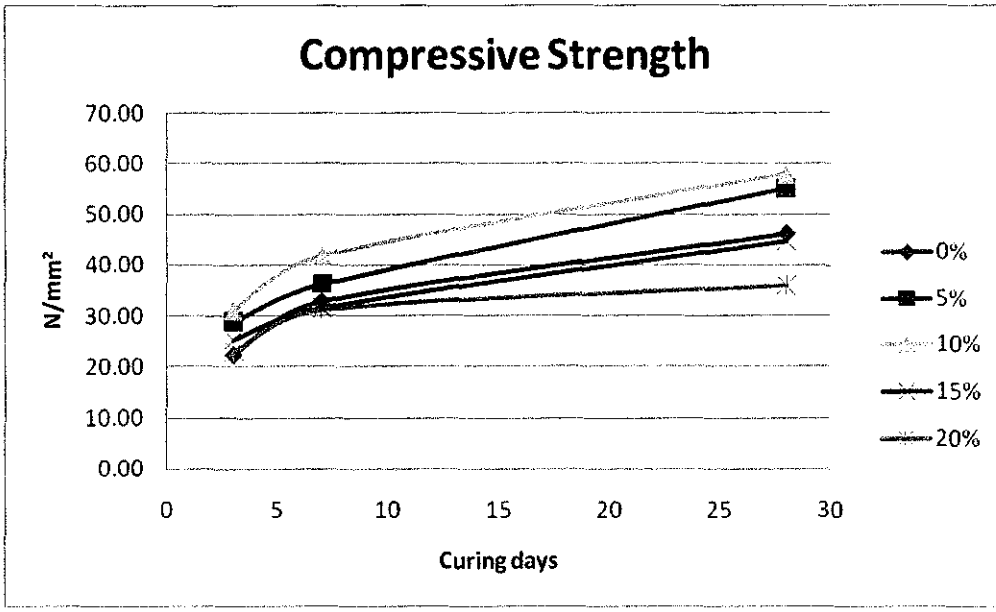


**Figure 4.1:** Graph of compressive strength

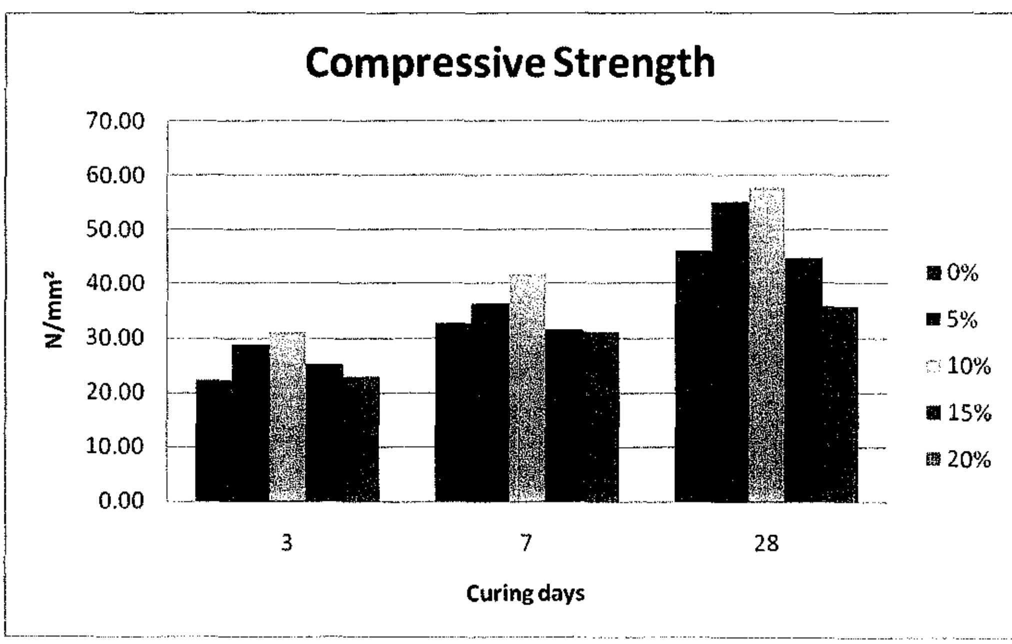


**Figure 4.2:** Bar chart of compressive strength

Graph and bar chart above show the compressive strength result. From the figure it can be interpreted that the concrete strength increases when the mud was added to the mixture of concrete. The result also shows that 10% of mud reacted well with the mixture of concrete. The result gives significant result by 30% increase compare to control specimen. First stage of experiment has proved that the mud can be use as cement replacement material (CRM).

### 4.1.2 Tensile Strength

The purpose of this experiment is to test the tensile strength of a cylindrical type sample for different percentage of mud blended concrete cubes.

**Table 4.2:** Result of split test

| | | (0%)<br>Sample | | |
|---|---|---|---|---|
| Days | 1 | 2 | 3 | Stress(Mpa) |
| 28 | 4.318 | 4.312 | 4.322 | 4.32 |
| | | (5%) | | |
| 28 | 4.592 | 4.529 | 4.562 | 4.56 |
| | | (10%) | | |
| 28 | 4.627 | 4.739 | 4.761 | 4.71 |
| | | (15%) | | |
| 28 | 4.567 | 4.544 | 4.589 | 4.57 |
| | | (20%) | | |
| 28 | 4.506 | 4.407 | 4.504 | 4.47 |

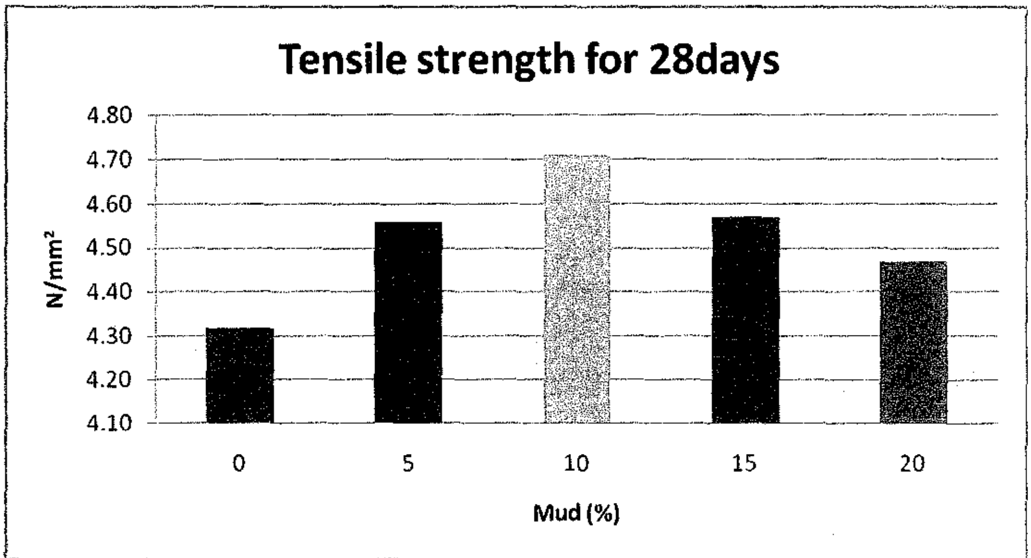


**Figure 4.3:** Bar chart of tensile strength

This bar chart explains about the effect of mud into increasing the tensile strength of concrete. Research shows that this mud has high calcium, silica and alumina content.

This chemical content increased the cement reaction hydration process. With this amount chemical the main hydration process calcium silicate hydrate and calcium hydroxide will react fast. This result also tells that 10% of mud gives the best strength compare to other mixture. There is no significant result compare to control specimen.

### 4.1.3 Porosity

The purpose of this experiment is to find the porosity or amount of empty space in concrete of mud blended concrete cube

**Table 4.3:** Result of porosity test

| Sample | $W_{air}$ | $W_{water}$ | $W_{dry}$ | Porosity | Average |
|---|---|---|---|---|---|
| | | | **0%** | | |
| 1 | 42.9 | 25.4 | 37.3 | 32.00 | |
| 2 | 44.1 | 25.9 | 38.3 | 31.87 | 33.66 |
| 3 | 37.7 | 24.5 | 32.8 | 37.12 | |
| | | | **5%** | | |
| 1 | 42.5 | 23.8 | 36.4 | 32.62 | |
| 2 | 42.5 | 23.8 | 36.3 | 33.16 | 32.14 |
| 3 | 43.2 | 23.3 | 37.1 | 30.65 | |
| | | | **10%** | | |
| 1 | 44.8 | 24 | 38.3 | 31.25 | |
| 2 | 45 | 24.1 | 38.4 | 31.58 | 31.43 |
| 3 | 45.8 | 24.5 | 39.1 | 31.46 | |
| | | | **15%** | | |
| 1 | 37.6 | 19.3 | 31.6 | 32.79 | |
| 2 | 36.5 | 19.9 | 30.7 | 34.94 | 33.88 |
| 3 | 36.4 | 19.3 | 30.6 | 33.92 | |
| | | | **20%** | | |
| 1 | 27.3 | 14.4 | 22.8 | 34.88 | |
| 2 | 27.3 | 14.3 | 22.8 | 34.62 | 34.54 |
| 3 | 27.2 | 14.3 | 22.8 | 34.11 | |

3 no's 1" x 2" cylindrical type sample for each mix were taken and submerged in vacuum bowl for 6 hour. Later the saturated weight and weight in water were measured. Than the sample were kept in oven for 24 hours and the dry weight were measured

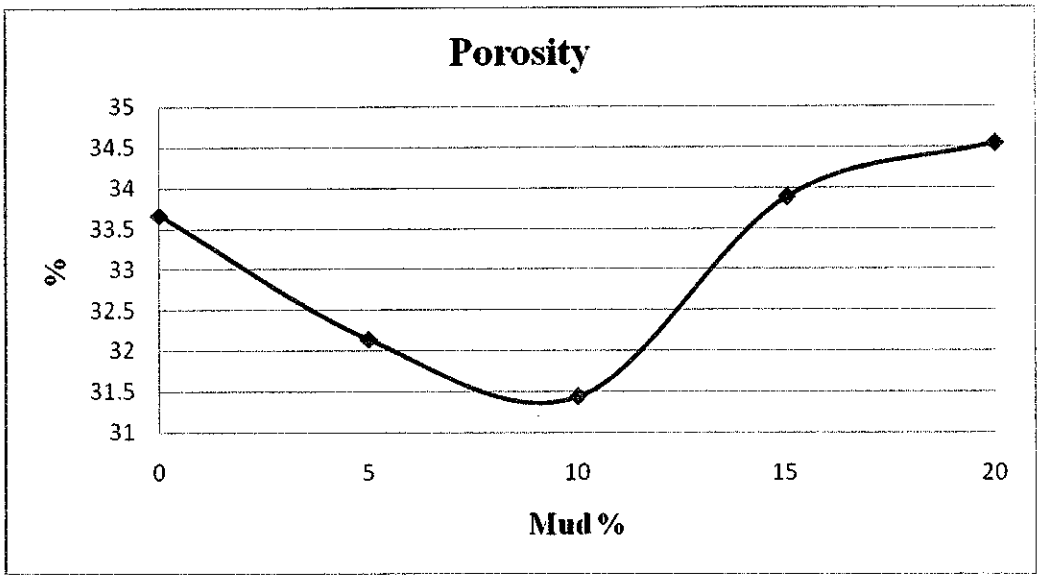


**Figure 4.4:** Graph of porosity level

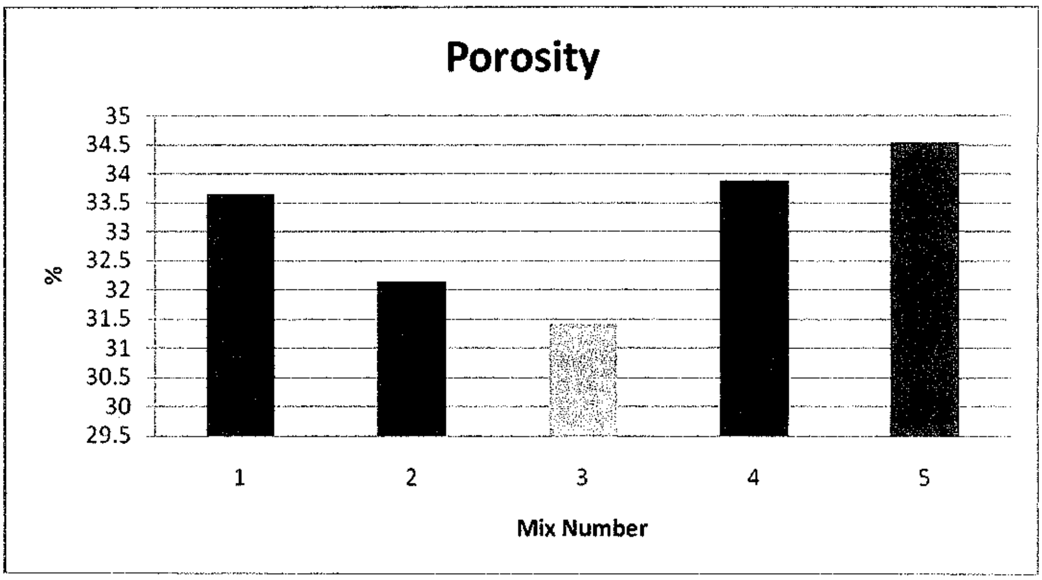


**Figure 4.5:** Bar chart of porosity level

Experts have widely agreed for decades that the use of pozzolana, or supplementary cementing materials, can reduce porosity. Since, low porosity gives high strength and last for a long time. This experiment is carried out to determine the effect of mud into reducing the void ratio between the mixture compounds. The degree of hydration or maturity of the concrete determines the porosity of concrete. During hydration calcium hydroxide, $Ca(OH)_2$ will react and increase the interlocking between the mixture. This graph and bar chart shows that mix number 3 or 10% of mud blended mortar gives the best result. The result is an evident that this mud can reduce the void of the material acting linearly to the curing date.

### 4.1.4 Integrity

The purpose of this experiment is to find the pulse travelling in between the concrete cubes. These values help to assume the integrity between the mixtures.

**Table 4.4:** Result of UPV test

| Sample | Surface 1 | Surface 2 | Surface 3 | Average for surfaces (μs) | Average pulse(μs) | Velocity(km/s) |
|---|---|---|---|---|---|---|
| | | 0% | | | | |
| 1 | 16.4 | 17.5 | 20.2 | 18.03 | | |
| 2 | 16.9 | 17.7 | 20.5 | 18.37 | 18.27 | 2.74 |
| 3 | 17 | 18 | 20.2 | 18.40 | | |
| | | 5% | | | | |
| 1 | 19.8 | 17.1 | 20.5 | 19.13 | | |
| 2 | 19.8 | 16.2 | 21.8 | 19.27 | 19.08 | 2.62 |
| 3 | 18.7 | 17 | 20.8 | 18.83 | | |
| | | 10% | | | | |
| 1 | 17 | 16.1 | 22.6 | 18.57 | | |
| 2 | 14.9 | 15.2 | 21.6 | 17.23 | 17.79 | 2.81 |
| 3 | 15.2 | 15.1 | 22.4 | 17.57 | | |
| | | 15% | | | | |
| 1 | 16.1 | 16.9 | 18.7 | 17.23 | | |
| 2 | 17.3 | 17.4 | 18.2 | 17.63 | 18.08 | 2.77 |
| 3 | 15.9 | 18.1 | 24.1 | 19.37 | | |
| | | 20% | | | | |
| 1 | 18.3 | 18.2 | 23 | 19.83 | | |
| 2 | 19.6 | 19.1 | 20.1 | 19.60 | 20.00 | 2.50 |
| 3 | 18.9 | 19.2 | 23.6 | 20.57 | | |

Table above shows the pulse travelling in between concrete cubes. This pulse value has been converted to velocity and with the value of velocity a graph can be produced as shown below. The relationship between the velocity of the ultrasound pulse and concrete strength is highly dependent on mix used.

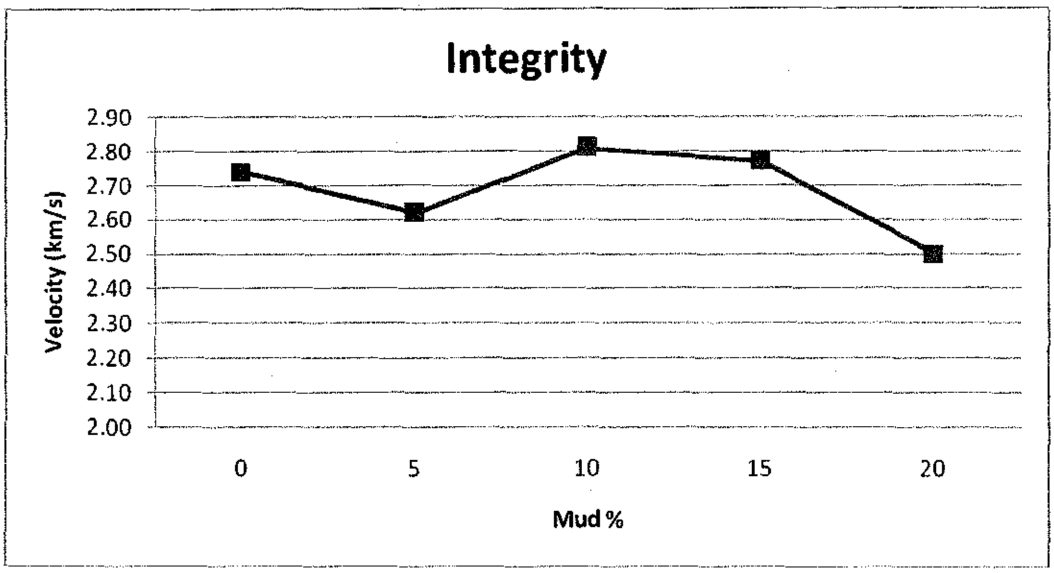


**Figure 4.6:** Graph of UPV test

In this experiment, high velocity gives better integrity with better strength and can last for a long time. Integrity between the mix compounds will reduce the void and make the concrete impermeable. This experiment shows that adding of pozzolanic material can reduce the permeability and increase the integrity. The combination of this mud with lime in cement increases the binding capabilities. This experiment proved that mix number 3 with 10% of Sidoarjo mud gave better integrity.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The primary goals of this thesis have been achieved at the end of this project. The oxide and amorphous content of this mud proved that this Sidoarjo mud have all the cementitious criteria. Beside that, the test also proved that the cementitious element of this mud is much better than OPC. Compressive strength gave significant increase in result by 30% compare to control specimen. Meanwhile for tensile and UPV there are no significant result. The result increased by 9% and 2.6% respectively. Mud also decreased the amount of void by 7%. With high amount of silica and alumina its gives better pozzolanic reaction. The second objective of this thesis, effect of this mud into mortar also gives a favorable result. The experiments which have been carry out proved that this mud can increase the strength, reduce the porosity and increase the integrity between the mixes. As for evidence all the results have been attached in the body of this thesis. At the end of this project it has been noticed that 10% of Sidoarjo mud can be utilized has cement replacement material.

## 5.2 Recommendation

This research to use this Sidoarjo mud as cement replacement material can be used as remedial to overcome the problem hat occur in East Jawa, Indonesia. Beside mitigate the flow to river or sea the government can use the mud for a better purpose. This will reduce the environment impact caused by this mud. Beside that, some other concrete base researches also need to initiate to prove the usage of this mud. The research on resistibility, durability and reliability also can be carried out to fill the gaps of understanding. In future, there should have investigations on this topic or related topic to enhance the usage of this mud.

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