A STUDY OF MODULUS RUPTURE AND WATER ABSORPTION OF CEMENT MORTARS WITH REPLACEMENT OF PALM OIL FUEL ASH (POFA)

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ABSTRACT

This thesis deals with the use of palm oil fuel ash (POFA) as the cement substitution to the Ordinary Portland Cement for the use of cement mortar. It is an attractive approach whereby POFA has been abundance in Malaysia and little research has been done on it. Furthermore, this research also involved the percentage of water absorption of each mix at 7^{th} day and 28^{th} day of cement maturation. The main objective of the study is to find out the best modulus of rupture (apparent tensile strength) from the various amount of POFA added into the mix and the best rate of water absorption from the samples. The tensile tests were carried out for different mortar beam samples with the used of strain gauge. Both 7^{th} day and 28^{th} day cement mortar maturation days were tested to compared its early strength and strength upon maturation. Graphs were plotted to make compares between the samples. The samples are then to be kept until all the testing is done on 7^{th} and 28^{th} days. The samples were then to be dry in oven for 24 hours before conducting the water absorption test. Dry samples were then immersed in water for another 24 hours to get its best water absorption rate. Data were tabulated and analysed. The optimum percentage of POFA that gives the optimum modulus of rupture for the cement mortar beam is 2% whereas for the water absorption, it can be concluded that as amount of POFA increased, the water will be less absorbed by the cement mortar due to POFA's fine properties that fill in the void in the cement mortars. The variation content of POFA was 0%, 1%, 2%, 3% and 4% by total cement weight.

ABSTRAK

Tesis ini berkaitan dengan penggunaan abu bahan api kelapa sawit (POFA) sebagai penggantian simen Portland biasa bagi penggunaan simen mortar. Pendekatan ini adalah menarik di mana terdapat banyak POFA di Malaysia telah dijadikan bahan buangan dan tidak banyak penyelidikan dijalankan. Tambahan pula, kajian ini juga melibatkan peratusan penyerapan air bagi setiap campuran pada hari ke-7 dan hari ke-28 kematangan simen. Objektif utama kajian ini adalah untuk mengetahui modulus pecah yang terbaik (kekuatan tegangan jelas) dari pelbagai amaun POFA ditambah ke dalam campuran dan kadar penyerapan air terbaik daripada sampel. Ujian tegangan telah dijalankan bagi sampel mortar yang berbeza dengan penggunaan strain gauge. Kedua-dua hari ke-7 dan hari ke-28 mortar simen telah diuji untuk berbanding kekuatan awal dan kekuatan pada kematangan. Graf telah diplot untuk membuat perbandingan antara sampel. Sampel kemudiannya akan disimpan sehingga semua ujian itu dilakukan pada hari ke-7 dan ke-28. Sampel-sampel akan dikeringkan di dalam ketuhar selama 24 jam sebelum menjalankan ujian penyerapan air. Sampe-sampel kering direndam di dalam air selama 24 jam untuk mendapatkan kadar penyerapan air yang terbaik. Data telah dijadualkan dan dianalisis. Peratus POFA optimum yang memberikan modulus optimum pecah untuk simen mortar adalah 2% manakala bagi penyerapan air, ia dapat disimpulkan bahawa penyerapan air akan berkurangan dengan meningkatnya amaun POFA. Kandungan pengubahan POFA adalah 0%, 1% , 2% , 3% dan 4% dengan jumlah berat simen.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Often in the construction field, buildings are generally made up of beams, columns, and slabs; it is clear that these structures are made from cementitious materials. Furthermore, there is no clear statement saying that these structures must be of conventional mixtures before any casting of the structures. With the increasing of population in the developing countries like Asian countries, the demand for more construction materials are increasing, also shortage of materials (Raut et al., 2011). Therefore, sustainable development in green technologies is one the important aspects that needs to be take into consideration for future development.

With the sustainable technologies that adopted for enhancement of quality of life and these developments are able to be measured by the means of economic growth and productivity. Different technology that adopted might serves different purposes, but they shared a common factor; whereby each and every one of the technology will serve one unique set of attribution that attracts the adopter (Ali, 2011). That is why with the adaptation of sustainable green technologies will bring up a new breath of life towards the construction field and thus bringing up industries that contribute green materials with a new line of business.

1.2 PROBLEM STATEMENT

With the rapid growth of population in the nation and the urbanisation, a shortfall of natural resources had come to its bottleneck. Furthermore, conventional production of construction material methods had emitted tonnes of unwanted pollutants to the environment. Agro-industrial waste disposal is one of the serious issues that come across the nation in recent years, for example, palm oil shell ash, rice husk and paper mill wastes. Subsequently, with the availability of the unwanted agro wastes, sustainable construction materials will be further evaluated in terms of its mechanical properties and environmental impact (Madurwar et al., 2013). For a greener environment, alternatives from the existing agro wastes had eventually showed some promising results in recent years of research; therefore further exploration towards agro waste is vital either in saving the environment from greater pollution or bringing up another field of business that brings profit from wastes.

Palm oil fuel ash (POFA) is one the common type of pozzolonic materials that is selected among many kinds of agro waste. Due to tropical countries like Malaysia, Indonesia and Nigeria are countries that grow abundant of oil palm fruits, getting localised waste materials from factories and mills are often accessible (Shafigh et al., 2012). Furthermore, from Shafigh, Mahmud, and Jumaat (2012) also states that POFA records a significantly higher and better result as compared with previous reported values and is much more economical compared to original uncrushed palm oil shell. On the other hand, POFA replacement improved the ultimate flexural and tensile strength of original mixture with the increased of POFA replacement level in the cementitious material (Aldahdooh et al., 2013). Since pass and current studies has revealed that having pozzolonic materials replacement in cementitious materials will eventually help in achieving greater results of flexural strength, which is why the research is vital for developing the use of green materials.

1.3 RESEARCH OBJECTIVE

The following are the research objectives throughout the study:

1.3.1 To find the best modulus of rupture (apparent tensile strength) with different percentage of additive substitution.

1.3.2 To determine the best rate of water absorption with different percentage of additive substitution at 7 and 28 days of curing time.

1.4 SCOPE OF STUDY

With the availability of oil palm shell from factory or any mill, by substitution a portion of POFA into the cement mortar will eventually help in reducing the agro waste in the industry itself. In addition, the research is very feasible to be carried out in Malaysia as agro waste from the oil palm industry is in abundance and this will also help in adopting a green technology in Malaysia for a greener future. Furthermore, as reference from previous researches, it was found that crushed oil palm shell is very helpful in the enhancement of flexural strength of the cementitious materials. Therefore, by taking POFA into consideration will definitely gain some significant results in achieving the objectives. Thus, by conserving a greener environment with recycled materials and further improved the mechanical properties of the current cementitous material can actually proof that this technology and method adopt will bring up a new life for the recycle industry as well as the construction industry.

CHAPTER 2

LITERATURE REVIEW

2.1 RECYCLED AGRO MATERIALS (PALM OIL FUEL ASH – POFA)

As the world moves towards a modern and urbanisation era, many tends to neglect the wastes that produced by the agricultural industry that has been an unsolved problem for some time. Rapid urbanisation in the era had eventually caused a declined of materials support for the building construction industry whereby the earth's resources are no longer able to sustain the development. Therefore, in order to satisfy the demand of the industry, disposal waste had become an alternative towards solving the above problems. Traditional method of construction is no longer able to survive if application of other product does not come in. The use of agro-waste materials in recent years had shown promising results and yet these waste are no longer just waste anymore. Research had done in terms of their physic-mechanical properties, methods of production and environmental impact to provide not only a solution to reduce agro waste but also to solve problems regarding shortage of construction materials (Madurwa et al., 2013).

The implementation of POFA into cementitous materials is observed to show some similar strength as compared to ordinary OPC cementitous materials but during early age of the materials, the materials do show some slower gain in strength (Awal & Abubakar, 2011). Nevertheless, numerous researches also showed that partial replacement of POFA into cementitous materials will have its limits. Even so, the partial replacement will eventually reduce the volume of waste in the palm oil industry rather than just being fly ash or filling up landfills with no other usage but pollution (Hussin et al., 2009).

On the other hand, the partial replacement of POFA eventually will help in reducing cost of raw materials since it cost lesser compared to normal quarry aggregates or natural aggregates. Furthermore, many researchers discovered that the potential of POFA does not limit to its big clinker form but a higher potential in the form of powder or ultrafine forms (Sata et al., 2010). Therefore, having agro-waste in cementitous materials will eventually help to bring up the potential in waste products, having more people to know about its potential; convincing the society and thus bring up another business and work opportunity for palm oil industry.

2.2 MODULUS OF RUPTURE (FLEXURAL STRENGTH)

Modulus of rupture of concrete is to be categorised as the bending strength of unreinforced beam, which depends on the beam sizes are also to be known as the apparent tensile strength of unreinforced beams; in this case POFA mortar beams (Bazant & Li, n.d.). The basic idea is to determine the tendencies of fracture developed when loading are exerted onto the mortar beams where micro-cracking are distributed along the boundary layers. Therefore, with additional of different POFA percentage will determine the effect of cracking and failure of the mortar beams. Bending strength is one of the important aspects can be seen in the cement made drainage where cracks often happen along the channel. With enhancement of bending strength of the cement channel the cracks can be solved. Since the channel is small, reinforcement bars will be impossible to solve the problem; by having POFA in the cement materials will eventually help in improving the cracking. The experimental of using beams are mitigating the collapse of a typical cement drainage channel (Namdar et al., 2013).

The cementitous materials that incorporate with POFA is a new class of green ultra-high performance fiber reinforced cementitous composites where the replacement volume may contained up to 75% of POFA content. Therefore, more research on the partial binder configuration is vital in determining its ultimate flexural strength test (Aldahdooh et al., 2013).

As mentioned earlier, at the early age of the materials the gaining of strength is slow but as the maturation of the material significantly, results obtained for 28th days shown results that are of stronger than early age which means that the material is fit to be used. As the percentage of POFA increased, the ultimate flexural strength increased as well (Aldahdooh et al., 2013). With the flexural strength alone does not able to confirm that the data are reliable, researchers had found out that with the increased of compressive strength, the flexural strength will eventually increase respectively. The results revealed that with ordinary cementitious materials the flexural strength only at the range of 2.13 to 4.93 MPa at 28th day but with POFA, the flexural strength gone up to a range of 4.42 to 6.99 MPa at 28th day (Aldahdooh et al., 2013). Therefore, these tests show that with increasing POFA content in the mixture, the flexural strength will increased as well as the compressive strength.

2.3 CRACK MORPHOLOGY

Cracks happened often due to over load that acted onto beams. Shear is the most discussed topic in terms of structural behaviour of any cementitious member. With a large shear force that acted onto the member, cracks known as shear cracks will eventually induced in the largest region where diagonal cracks can be seen clearly. With this problem arising throughout the industry, there is still no one solutions as design are differing with different country and designer to solve the nature of shear cracks (Alengaram et al., 2011). Due to many cases of cracks on beams, therefore prediction of crack pattern can be done and compared with experimental ones. This is basically structures with no shear reinforcement will eventually induced cracks along it.

2.4 WATER ABSORPTION

Cement itself is very reactive with water. Since the samples are of mortar; only consists of cement and fine aggregates with POFA, it is important to test for water absorption. This is due to that the amount of POFA will eventually affect the amount of water to be absorbed into the mortar itself. Voids are pores that will develop even how well the mix is done, therefore the function of POFA is to fill up the voids and thus strengthen the mortar. The increased of POFA in the cement mortar will decrease the water that is to be absorbed by the mortar; this is due to the voids are to be filled up by the POFA (Naganathan & Linda, 2013). Furthermore, due to incomplete compaction of mortar that shown by construction industries out there nowadays, that lead to the lowering of strength of mortar, that is why studies need to be carried out to ensure problems like these will be improved will the additional of POFA which will help in filling up voids while casting (Shah & Pitroda, 2013).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all the mode of testing and the preparation of materials in determining the flexural strength, crack morphology and water absorption will be explained in detail to give a clear picture on how these tests will work. Furthermore, related tests that will be conducted in this part will eventually support the findings in previous chapter. All of the tests conducted are to fulfil the objectives of the research. In addition, the purpose of this chapter will also give relevant information to every personnel on how materials will be selected and all the tests in detail.

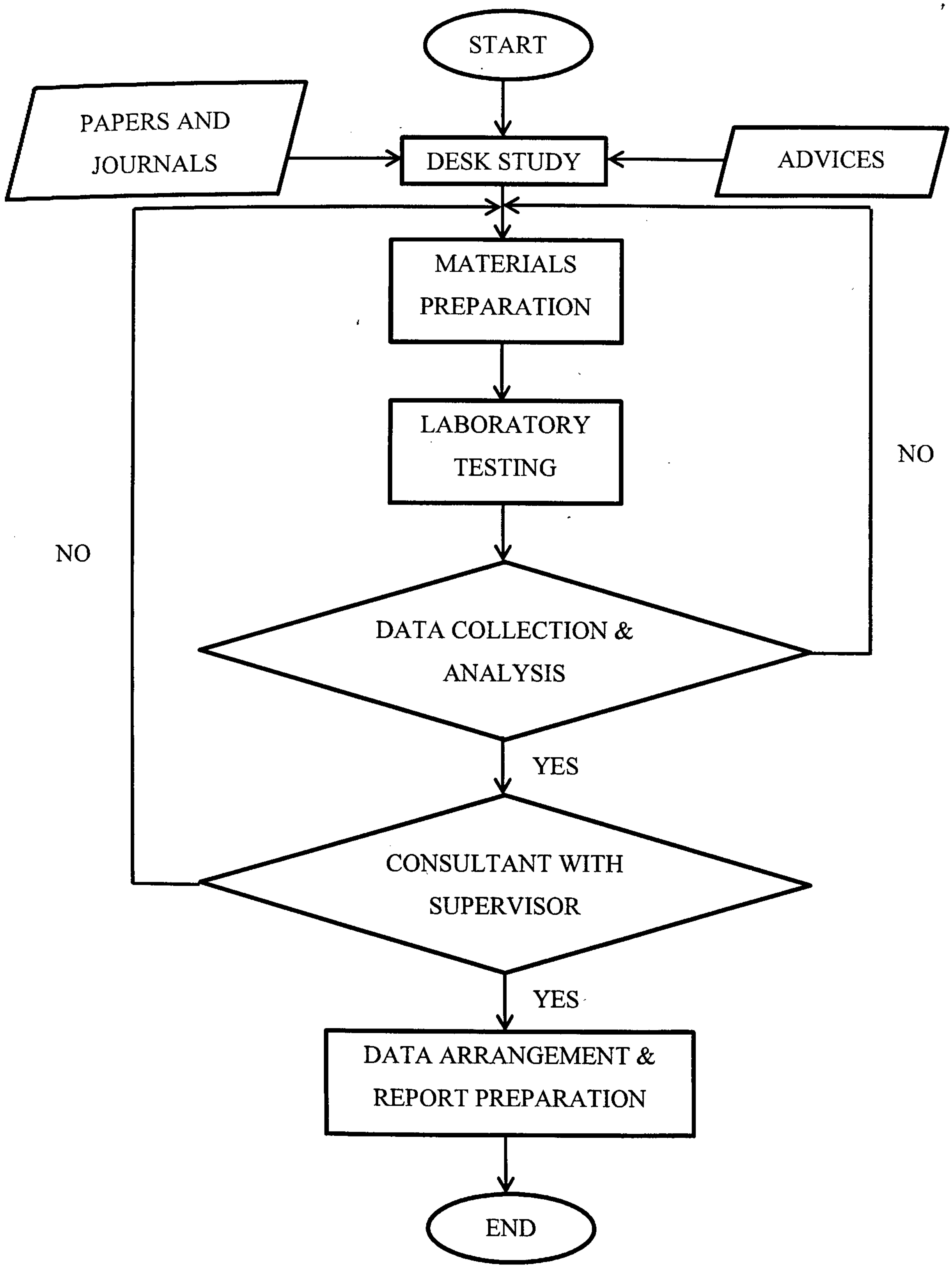
All the preparation works and testing will be carried out at the Concrete Laboratory in University Malaysia Pahang in which the laboratory are equipped with state-of-the are equipment where all the tests can be done smoothly. Testing involved are flexural strength test where graphs to be obtained are force versus deflection graph and force versus time graph. These data will eventually show how the materials react in such a way to either improve the cement mortar or vice versa.

3.2 DESK STUDY

For this research, gathering of data and papers from previous studies is very important and having numerous discussion with supervisor will eventually gather more constructive ideas to further improve the method for any testing as stated. Therefore, suggestion from lab technician and a few more experienced personnel are very helpful in developing the best experimental method in terms of materials preparation, cement mortar batching and testing methods.

Since the materials selected are of palm oil fuel ash (POFA) and fine sand, in terms of materials collection and preparation are the vital aspects in determining the results of the experimental testing. Therefore, mode of collection and preparation requires a standard methodology to prevent distortion of data.

3.3 FLOW CHART



3.4 PREPARATION OF MATERIALS

In this section, all the materials involved in the experimental state will be explained clearly to ensure the materials are fit to be used for the entire experimental period. The important aspect includes collection of materials, storage of materials and usage of materials will be explained.

3.4.1 Ultrafine Palm Oil Fuel Ash (POFA)

As from the findings in literature review, stating that recycled agro materials actually possesses potential in terms of enhancing the flexural strength of the beams. POFA is a by-product from the burning of palm oil husk which eventually has no function to the palm oil industry. There are many different percentage of POFA that used in the experiment, but from the findings, there are promising results with 10% to 40% aggregate replacement but the research is more the concrete beams; therefore for this thesis paper of cement mortar beams, the percentage of replacement is of 0%, 1%, 2%, 3% and 4% of cement replacement. Furthermore, no matter the research are of concrete beams or cement mortar beams, it is best for one to perform aggregate replacement with ultrafine POFA in which having a better bonding with Ordinary Portland Cement (OPC). Therefore, it is best that palm oil kernel that had been grinned are to be dry at room temperature to make sure the POFA is not too wet which might affects the casting results later. After drying to room moisture, only POFA that passing 300μm will be used for the research.

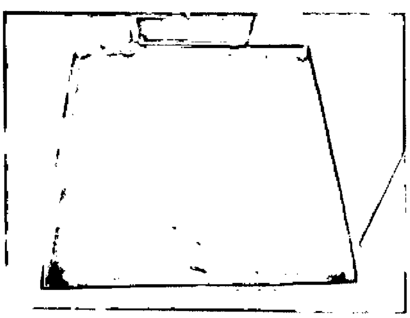


Figure 3.4.1.1: Drying of ultrafine POFA.

3.4.2 Fine Sand

Since the research is on cement mortar; which complies of 50% of the mortar content, the sand that is to be chosen must be of pure sand which does not consist of any clay or other contaminant in the sand. Sand is the fine aggregate that will filled up the void between the cement mortars, so it is important to minimise the error caused by fine sand. This is due to clayey or any other sand combination might cause some unwanted distortion of data during the curing process of the cement mortar. Furthermore, if clayey sand is chosen, there is a need to perform extra testing to identify the clay soil content in the particular sand content. Due to time constraint, collection of pure river sand is vital for this research to minimise the distortion of data.

3.4.3 Ordinary Portland Cement (OPC)

In the industry, there are numerous types of cement that is available; but for this research, OPC is sufficient to fulfil the requirement as bonding agent between fine river sand and POFA. This is because for construction industry, OPC is widely used; regardless of any branding of OPC, can be considered as a worldwide material which function as bonding agent as concrete in the concrete mix design. Therefore, for cement mortar, OPC is the main bonding agent.

3.4.4 Water

For a typical mix design, water ratio is very important for the workability of the cement mortar mix. As a common practice, 40% from the weight of the cement used is the ideal water ratio for a mix design. Furthermore, water that is used is very important; water used must be free of any chemical agents or pollutants which will eventually affect the quality of the cement mortar after curing days. The same water that is used for the mix design will apply for the curing water; both part of water serves as an important agent in the strength of the cement mortar.

3.4.5 Strain Gauge (5mm)

This equipment serves as simple yet sensitive tools in measuring the strain of the materials. The strain gauge arranges a long and thin conductive strip in which it has a zigzag pattern that arrange parallel lines whereby if there is any stress amount subjected onto the array of conductive lines, there will be a larger strain measurement over the effective length of the conductor surface that will trigger a change in resistant. The size of the strain gauge selected is of smaller size is due the beam size for testing is of small size. For economically purposes, 5mm strain gauge is sufficient. The strain gauge will be glue at one of the surface of the beam one day before testing; further use of the strain gauge will be explained in next section.

3.5 PREPARATION OF SPECIMENS

As mentioned earlier the specimen, cement mortar beam are to be cast are of small size; which measures 100mm x 100mm x 50mm. Percentage of POFA are 0%(controlled), 1%, 2%, 3% and 4%.

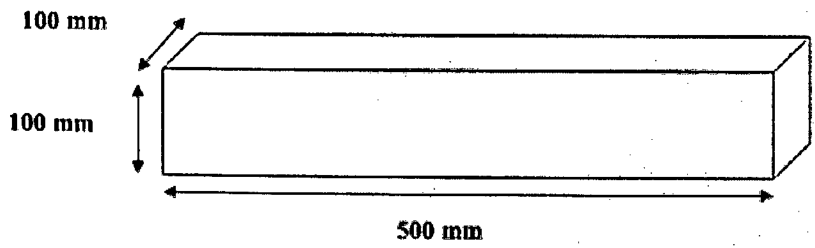


Figure 3.5.1: Dimension of beam.

Before casting of plain cement mortar, the materials are to be prepared as below:

Table 3.5.1: Proportion of materials for controlled beam.

Materials	Amount (kg)
Water	2.4
OPC	6.0
Fine aggregate (Fine River Sand)	6.0
POFA	0.0

Table 3.5.2: Proportion of materials for 1% cement replacement.

Materials	Amount (kg)
Water	2.40
OPC	5.94
Fine aggregate (Fine River Sand)	6.00
POFA	0.06

Table 3.5.3: Proportion of materials for 2% cement replacement.

Materials	Amount (kg)
Water	2.40
OPC	5.88
Fine aggregate (Fine River Sand)	6.00
POFA	0.12

Table 3.5.4: Proportion of materials for 3% cement replacement.

Materials	Amount (kg)
Water	2.40
OPC	5.82
Fine aggregate (Fine River Sand)	6.00
POFA	0.18

Table 3.5.5: Proportion of materials for 4% cement replacement.

Materials	Amount (kg)
Water	2.40
OPC	5.76
Fine aggregate (Fine River Sand)	6.00
POFA	0.24

3.5.1 Method of Cement Mortar Mixing

After obtaining all the mix design, casting procedure of the cement mortar is an important step to ensure the quality of cement mortar. The materials will be added in accordingly and mixing time is advised to be of 10minutes. The mixing process is as follow:

- Make sure the mixer is clean; no any other leftover dust or dried paste around the mixer.
- As the mixer is turn on, water will be added into the mixer according to the cement-water ratio.
- Add in the percentage of POFA replacement; mix evenly.
- Add in OPC and mix thoroughly.
- Add in sand into the mixer and then mix for 10 minutes; ensure the mixture is mixed evenly.
- Pour the mixture into moulds in 3 consecutive layers and vibrate for 30 seconds for each layer to ensure air trapped during pouring is expelled.
- Specimens are left to dry for unmoulding the next day; covered with wet sacks.

3.5.2 Curing

After one day of leaving the paste to dry up, unmoulding will be done and the specimens now will be cure in water pool. This process is important as a hydration process for the cement mortar to gain its strength and to ensure hydration also take place for bonding inner part of the cement mortar. Water will filled up all the micro pores of specimens. The curing duration will be done in 2 stages for experiment purposes; 7 days and 28 days to check for its flexural strength.

3.6 TESTING MODE

The main focus of this research is to check on the beams' performance with different aggregate replacement percentage on the mechanical and physical properties. Before any testing that is to be done on the specimens, strain gauge will be attached on the specimen a day before. This is to ensure the adhesive between the strain gauge and the specimen is totally dry. The main testing that will be conducted is the flexural strength test with the used of Universal Tensile Machine (UTM).

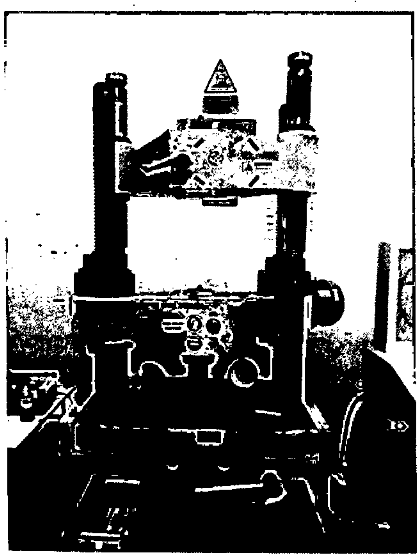


Figure 3.6.1: Universal Tensile Machine (UTM).

3.6.1 Modulus of Rupture Test

The specimens are to be subjected to a 3 point loading to check for its bending strength with different percentage of aggregate replacement. The results will be recorded by the data logger which later to be transferred to computer for further analysis. Before testing, strain gauge is to be glued onto the beam surface. The position of the strain gauge is very important; one third of the beam's length from each side will be the best position to attach the strain gauge. The following are the steps for experimental setup and testing:

- Specimen took out from curing water a day before will be cleaned with abrasive paper and mark gauge installation position.
- Adhesive are put onto the respective location and evenly spread out the adhesive to a semi-dry before placing the gauge on the mark.
- The specimen is left for a day before testing.
- The specimen will be placed onto the support (roller support) with the same position of the gauge but at another face of the specimen.
- The longitudinal section of the specimen will be the face for loading.
- The loading applied must be of care as the specimen are to be classified as sensitive to sudden shock or force applied and will failed before recording any data.
- After the loading are in position, loading will be applied slowly; data will start to record to its highest load.

3.6.2 Crack Morphology

After the modulus of rupture strength test, the specimen will be analysed in terms of its crack morphology whereby the crack pattern will be taken. The higher the percentage of aggregate replacement does not mean a higher strength and better crack for the specimen.