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A Simulation Model of Solid Concrete Beam Containing Palm Oil Fuel Ash (POFA) And Expeneded Polystyrene (EPS) Using Finite Element Method

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Abstract: First Concrete beam construction has contributed to a rise in the emission of carbon dioxide (CO^2) gas, which is the key cause of global warming. To solve the effects, the materials for making concrete can be replaced by other environmentally friendly materials. In this case for concrete beam construction, Palm Oil Fuel Ash (POFA) and Expanded polystyrenes (EPS) would be used to substitute several percent of cement and aggregate. The use of POFA can produce high strength concrete and can also reduce waste disposal and EPS can produce lightweight concrete. This study is focusing on to analyse the silica structure of POFA by using X-Ray Diffraction (XRD) and to determine mechanical properties of concrete containing POFA and EPS by using ABAQUS software. For this project, the main factor why ABAQUS software was used as analytics software because the software is specifically designed to analyse advanced structural and heat transfer. For both very small and very large structures, it is designed for both linear and nonlinear pressure analyses. This ABAQUS software will help to compare between normal concrete and concrete containing POFA and EPS. The information contains the appropriate percentage of POFA and EPS in the solid concrete beam where performance in terms of displacement, stress and strain.

Keywords: EPS, POFA, Silica Structure, ABAQUS, Displacement, Stress, Strain

1. Introduction

Concrete is one of the most widely used for construction materials in the world. Concrete is selected for its durability, strength and beauty from buildings and hardscaping to infrastructure. Since concrete is commonly used for construction materials, many civil engineers are trying to find an alternative way to make more effective use of concrete. Lightweight concrete can be defined as a form of concrete containing an expanding agent in that it increases the volume of the mixture while at the same time

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giving additional qualities. Furthermore, properties of lightweight can be the same as normal properties and it is lighter than normal concrete. Lightweight concrete is most commonly used for a non-structural member in construction and because of that, there are some requirements and characteristics have to consider before it is used as one of construction materials.

For this paper, Palm oil fuel ash (POFA) and expanded polystyrene (EPS) were used as replacement material in concrete which POFA is replacing the cement and EPS replacing the aggregate. POFA is a by-product of thermal power plants with biomass from which oil palm residues are burned to generate electricity and Malaysia is one of the major palm oil producers with about 41.00 % of global supplies in 2009–2010 [7]. POFA also has been known to possess a pozzolanic property which are silicate-based materials that react to (consume) the hydroxide of calcium produced by hydrated cement to form additional cement materials. Currently millions of tons of waste polystyrene are produced in the world and it is will caused pollution and is harmful to the ecosystem [3]. Local and international environmental laws have also become more inflexible, which makes disposal of this waste more costly. Therefore, the use of waste polystyrene in concrete manufacturing not only addresses the question of disposing of this ultra-light solid waste (up to 95.00 % air), it also helps to conserve natural resources [3].

Finite Element Analysis (FEA) software is used to analyse and solve engineering problem for complex geometries. It is common methods used to analyse static and dynamic, numerical method for solving problems by mathematical. Due to its versatility in creating geometry and material modelling, ABAQUS was selected for the purpose of modelling and analysis of the concrete beam in this study. All the data that has been used to put in ABAQUS software was from a previous study.

1.1 Problem Statements

Malaysia has been facing a problem in disposal POFA, approximately 3 million tons of POFA produced in Malaysia at 2007 [11]. From an external view, the producing of 1 tons of cement produces approximately 1 tons of CO^2 directly. Therefore, cement production accounted for 7.00-10.00 % of the world's overall CO^2 emissions [2]. As well as, the waste polystyrene will cause pollution and harmful to the ecosystem. It is can be used in many applications for example it is can be used as an ice box to keep any product either in temperature cold or hot and for this project were used as the replacement of aggregate in the lightweight concrete because it is extremely light as contain up to 98.00 % voids and easily combine with concrete [8]. Normal concrete has a high density while EPS can produce lightweight concrete and by replace EPS as fine aggregate, it can produce lightweight concrete beam. Therefore, this project is concerned the elimination of waste by the use of POFA and EPS in concrete mixtures because POFA and EPS have a lot of advantages when it is added into the concrete.

1.2 Objectives

1. To analyse the silica structure of POFA by using X-Ray Diffraction (XRD)
2. To compare the mechanical properties between normal concrete and concrete containing EPS and POFA using finite element method.
3. To analyse the displacement, stress and strain on the solid concrete beam containing EPS and POFA

1.3 Scope of Study

In this final year project, it will focus on mechanical properties of POFA and EPS as cement and fine aggregate as replacement material in concrete mix. POFA is known to contain a high amount of silica and the POFA samples were analyses using an X-Ray Diffraction (XRD) to determine their silica composition. The solid concrete beam is analysed using finite element analysis software called ABAQUS. The software is also used to analyse the displacement, stress and strain of solid concrete beam containing EPS and POFA. The result obtained from the Abaqus in terms of displacement and stress is used to verify the experimental result. The percentage of POFA contain in solid concrete beam is 10% and the percentage of EPS that contain in concrete are 0.00 %, 10.00 %, 20.00 % and 30.00 % while 0.00 % of POFA and EPS use for the control sample for the mixture of concrete.

Table 1: Percentage of POFA and EPS

Percentage of Palm Oil Fuel Ash (POFA)	Percentage of Expended Polystyrenes (EPS)
10%	0%
10%	10%
10%	20%
10%	30%

2. Literature Review

This part will review the detail of this final year project and consider various material and information needed to accomplish this project

2.1 Lightweight Concrete

The main specialities of lightweight concrete are its low density and thermal conductivity. Its benefits are a reduction in dead load, higher building speeds and lower shipping and handling costs. Particularly, lightweight concrete can be categorized into three groups:

i. No-fines concrete
ii. Lightweight aggregate concrete
iii. Aerated/Foamed concrete

2.2 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is a by-product of thermal power plants with biomass from which oil palm residues are burned to generate electricity. Malaysia is one of the major palm oil producers with about 41.00 % of global supplies in 2009–2010. POFA is greyish in colour, with rising proportions of it being dark coal unburnt. Its chemical composition indicates the presence of high quantities of silica, which is considered to have high potential to serve as replacement for cement and porcelain. The large quantity of freely obtained silica from this source provides a cheap silica alternative for many industrial uses [5]. Palm oil waste has been one of the threats facing the palm oil industry as such waste is collected in large quantities alongside palm oil mills and in the landfills. The palm oil waste generates undesirable toxic gases such as CO_2, thus contributing to pollution of the environment [4].

2.2.1 POFA as the Pozzolanic Material

The amounts of LOI and SO_3 for pozzolanic is in limits of 10.00 % and 4.00 % as specified by ASTM C618. The content of silica ranges from 43.60 % to 67.72 % of the total POFA components. It is evident from the chemical composition of POFA that silica or alumina are the main component of POFA. Though in the presence of calcium oxide (CaO) or calcium hydroxide ($Ca(OH_2)$), silica and alumina have no cementing properties of their own. In the pozzolans silica and alumina react and form cemented materials. However, due to the operating system in palm oil mill the chemical composition of POFA can be varied [1]. The content of silica oxide in pozzolans can react as a result of the hydration process with calcium hydroxide ($Ca(OH_2)$) while the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) which is a gel compound. These reactions also reduce the calcium hydroxide content. This contributes to the strength of the concrete and makes concrete stronger and denser durability improved. The quality of silica primarily contributes to the pozzolanic reaction, and is considered an adequate partial replacement of cement. While the (SiO_2 + Al_2O_3 + Fe_2O_3) ranges from 52.11 % to 79.13 % of the total POFA components, which is responsible for the formation of additional C-S-H gels of calcium hydro silicate in concrete mixtures [4].

2.3 Expended Polystyrene (EPS)

Expanded polystyrene (EPS) is a lightweight composite of cellular plastics composed of small spherical shaped particles composed of around 98.00 % air and 2.00 % polystyrene. EPS is a solid, durable, closed-cell foam with a typical range of 11 to 32 kg/m^3 of density. It is usually white and made of pre-expanded beads made of polystyrene [10]. Due to the EPS's low density, being hydrophobic, thermal insulation, non-absorbent, closed cellular, and low cost, it is primarily used as packaging material, but is also used as insulating materials in construction industries.

2.4 X-Ray Diffraction (XRD)

X-ray powder diffraction (XRD) is a rapid analytical technique primarily used to identify a crystalline material in a phase and can provide information on the unit cell dimensions. The substance analyzed is finely ground, homogenized and defines the average composition of the bulk. The angle between the incident and the diffracted rays is a key component of all diffraction. Powder diffraction and single crystal diffraction vary beyond that in instrumentation

2.5 Finite Element Method (FEM)

The Finite Element Method (FEM) is a numerical solving problem technique that is represented or can be formulated as functional minimization by partial differential equations. As an assembly of finite elements, a domain of interest is represented. In terms of the nodal values of a physical field which is sought, approximating functions in finite elements are calculated. With unknown nodal values, a continuous physical problem is translated into a discretized finite element question. It is important to solve a system of linear algebraic equations for a linear problem. Using nodal values, values within finite elements can be retrieved. It is worth mentioning two characteristics of the FEM that, firstly, piece-wise approximation of physical fields on finite elements provides good accuracy even with simple approximation functions (increasing the number of elements that we can achieve some accuracy) and secondly, approximation position leads to sparse equation systems for a discretized problem. This helps to overcome issues with very large numbers of unknown nodal [6].

2.5.1 Mesh Generation In ABAQUS

Abaqus/CAE may use a range of meshing techniques to mesh models of distinct topologies based on the Abaqus/CAE user guide. You may select the technique used to mesh a model or model area in certain cases. Only one method is applicable in other instances. Varying levels of automation and user control are provided by the various meshing techniques. In Abaqus/CAE, there two meshing methodologies that are available: top-down and bottom-up.

Top-down meshing creates a mesh by working down to the individual mesh nodes and elements from the geometry of a part or area.

1. Structure Meshing
2. Swept Meshing
3. Free Meshing

Bottom-up meshing creates a mesh to construct a three-dimensional mesh by working from two-dimensional entities (geometric faces, faces of elements, or two-dimensional elements). Bottom-up meshing techniques can be used to mesh only solid three-dimensional geometry using all hexahedral elements, or almost all of them.

3. Research Methodology

The methodology of this research needed to be done according to the steps systematically to get actual and accurate data whether it is theory or practically. This chapter describes the methodology of using X-Ray Diffraction (XRD) to analyse silica structure of palm oil fuel ash (POFA) and ABAQUS computer software to perform finite element method on solid concrete beam containing expended polystyrene (EPS) and Palm oil fuel ash (POFA) using finite element method. The finite element method will verify experimental result and analyse the solid concrete beam containing EPS and POFA in terms of displacement, stress and strain in concrete.

3.1 X-Ray Diffraction (XRD)

X-Ray Diffraction (XRD) method was used to analysis the silica structure of palm oil fuel ash (POFA) which POFA samples were subjected to XRD using an X-Ray Diffractometer. Below is the step using The X-Ray Diffractometer Model Bruker D8 advance.

3.2 ABAQUS/CAE

ABAQUS/CAE is the Complete Abaqus Environment, which offers a quick, consistent interface to construct Abaqus models, apply and track ABAQUS jobs interactively, and evaluate Abaqus simulation performance. ABAQUS/CAE is divided into modules, in which a logical element of the modelling process is described by each module for example, geometry definition, material properties definition, and mesh generation. A model can build up as switch from module to module. ABAQUS/CAE creates an input file when the model is complete, which you send to the result of the ABAQUS analysis. ABAQUS/Standard or ABAQUS/Explicit reads the ABAQUS/CAE-generated input file, performs the analysis, sends ABAQUS/CAE information to allow you to track job progress, and generates an output database. Finally, to read the output database and display the results of analysis, use the Visualization module.

3.3 Structural Modelling

3.3.1 Specification of Beam

The concrete beam used in this research is 500 mm X 150 mm X 150 mm. Concrete grade 25 is used and the pointed load is 30 kN. A sketch of every part is created independently using ABAQUS, it can be force out in any direction.

3.3.2 The Data for Material

The data were used for this paper is get from previous study.

Table 2: Mechanical Properties of Concrete Containing EPS and POFA EPS [9]

Specimen	Mass Density (kg/m^3)	Young's Modulus, E (GPa)	Poisson's Ratio, v
0%POFA + 0%EPS	2400	30e9	0.3
10% POFA + 0% EPS	2335	24e9	0.2085
10% POFA + 10% EPS	2248	20e9	0.2195
10% POFA + 20% EPS	2126	18e9	0.2335
10% POFA + 30% EPS	2011	14e9	0.242

4. Result and Analysis

This chapter discusses about the result and analysis data gathered from the XRD which is about silica structure of POFA and the FEA software which is about Abaqus with different percentages of material design. There are five models created and meshed in Abaqus. The result obtained from Abaqus is deformation, displacement, stress and strain in concrete. Finally, when the solution is complete, the results can be viewed. These results may be of colour contour plots, line plots, or simply lists of degrees of freedom for each node. It is analysis phase where the results of analysis are reviewed through graphics and graph. The results are compared to determine the optimum percentage of EPS and POFA replacement for a good performance of solid concrete beam. The results are then verified with the experimental results.

4.1 Data Analysis of XRD

As a function of the angle between the incident and the diffracted beams, the X-Ray Diffractometer is a mechanical instrument for obtaining X-ray intensities. The product of the phase diagram (called a diffractogram) that shows the crystalline phases is shown in the Figure 1. Figure 2 illustrates that after treatment, the peaks increased. Thus, because of the silica content, the treated POFA is expected to offer more compressive strength. This are the result of a previous experiment under the same title, where POFA sources are from the same factory and use the same laboratory tests.

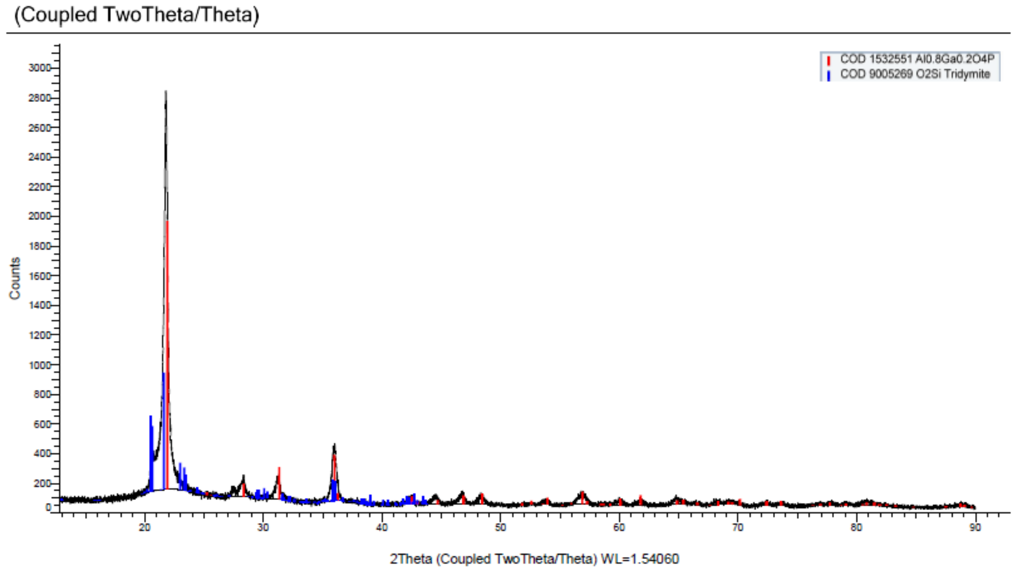

Figure 1: X-Ray Diffraction (XRD) spectra for the POFA

4.2 Data Analysis of ABAQUS

4.2.1 Displacement of Solid Concrete Beam

The graph of Displacement vs True Distance obtained from ABAQUS is used to compare between normal solid concrete beam (controlled) with solid concrete beam contained 10.00 % POFA with 10.00 %, 20.00 %, and 30.00 % of EPS in a same graph as shown in Figure 2. The graph is created directly using Abaqus as it has the functionality for users to combine multiple data into a single graph to easily observe the data.

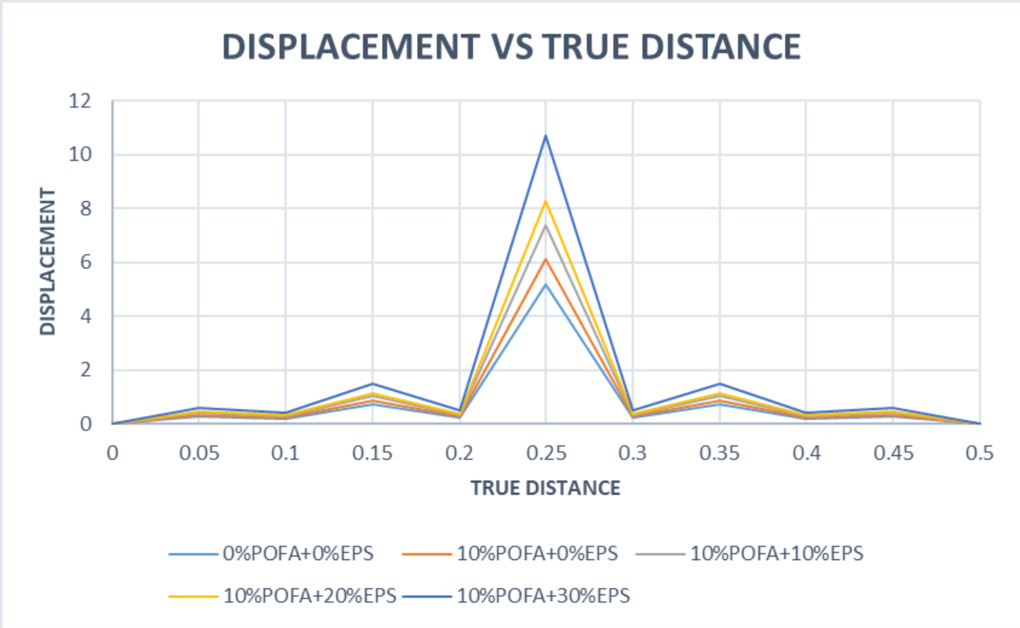

Figure 2: The Graph of Displacement vs True Distance

The simulation and the graph of the deflection of beams were produced after apply 30 kN on the centre point of the solid concrete beam. Based on the graph, the dark blue line which is for 10.00 % POFA + 30.00 % EPS show the highest displacement compared to the controlled and 10.00 % POFA with 0.00 %, 10.00 %, 20.00 % and 30.00 % of EPS. This is because the bonding of cement concrete mix is weakened by the presence of EPS.

4.2.2 Stress and Strain of Solid Concrete Beam

Figure 3 show the graph of vertical Stress over Strain for each of the sample of solid concrete beam. The legend indicates the colour for each percentage. The stress value was calculated at the load and support of the centre point.

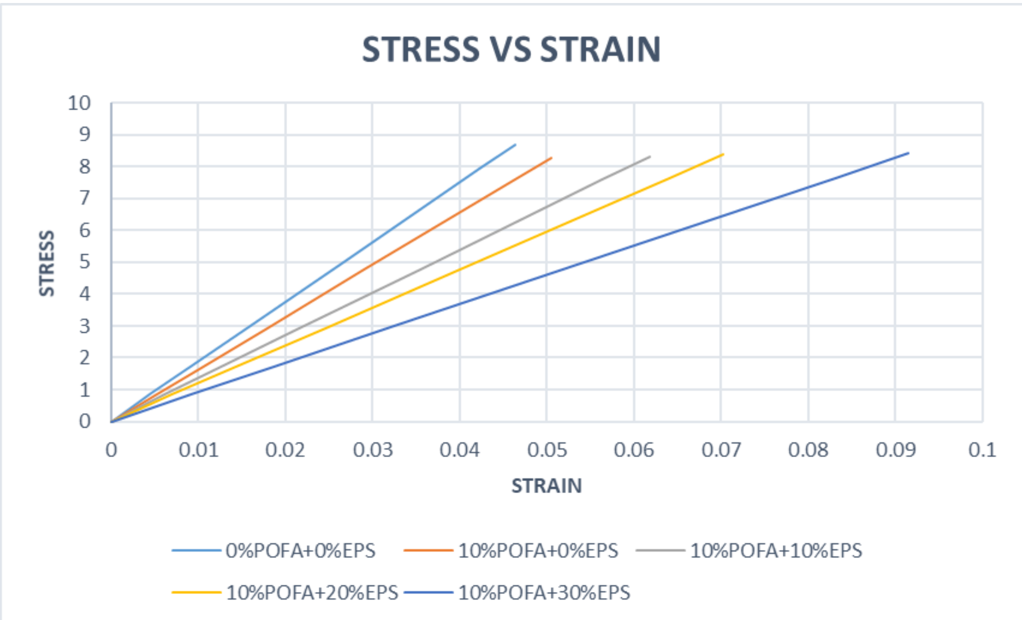

Figure 3: The Graph of Stress vs Strain

Based on the graph, stress is directly proportional to the strain. The dark blue line which is for 10.00 % POFA + 30.00 % EPS show the lowest strain compared to the others. Its mean that the sample of solid concrete beam containing 10.00 % POFA + 30.00 % EPS is the lowest strength from the controlled and 10.00 % POFA with 0.00 %, 10.00 %, 20.00 % and 30.00 % of EPS. The most significant property of concrete is strength and it tests how much load concrete structures can bear before they collapse [2].

5. Conclusion

In conclusion, the silica structure of POFA was analysed by using X-Ray Diffraction and the five structural model of solid concrete beam are analysed using Finite Element Analysis (FEA) which is ABAQUS software with their respective material behaviour and properties. The results of the analysis are analysed based on the performance of the models in terms of displacement, stress and strain. Based on the analysis, the following conclusions are made:

i. The silica structure of POFA was analysed by using XRD, and the results are observed and analysed.

ii. The results were compared between the normal solid concrete beam with the solid concrete beam containing POFA and EPS and show decreasing pattern in the performance of solid concrete beam are shown disregarding the increasing of percentage from normal concrete to 10.00 % POFA + 30.00 % EPS.

iii. The graph of displacement versus distance and stress versus strain are also obtained from Abaqus software. The strength of normal solid concrete beam is higher than 10.00 % POFA with 0.00 %, 10.00 %, 20.00 % and 30.00 % EPS.

5.2 Recommendation for Improving Results

There is always need a progress for better and more precise outcomes for any research project. In modelling, there are also have software limitations and technical challenges. For this project, there are the recommendation to improve the results:

1. For meshing process, it is recommended to set the mesh size as smaller as possible to obtain more accurate results because the size using for the project is a little big.
2. The percentage of POFA can vary more like 5.00 %, to 30.00 % because the optimum value is 10.00 % - 20.00 %.
3. Extra data for the solid concrete beam can be obtained like plasticity data since this data can generate a crack pattern in ABAQUS software.

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