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A Simulation of Solid Concrete Beam Containing Expanded Polystyrene Beads (EPS) and Palm Oil Fuel Ash (POFA) using ABAQUS Software

Muhammad Fauzi Mohamad Rawi[1], Mohamad Hairi Osman[1]*, Mohd Eizzuddin Mahyeddin[1]

[1]Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Nowadays, so much waste material was dumped and produced by the industrial sector to increase the economy by maximize the production. Also concrete beam has contributed to a rise in the emission of carbon dioxide (CO_2) gas, which is the key cause of global warming. In order to minimise the problem, concrete materials may be replaced by other environmentally friendly materials. In this research, the Palm Oil Fuel Ash (POFA) and Expanded Polystyrene beads (EPS) were used as replacement material. The objective of this paper was to focus on replace several percent of cement and aggregate in solid concrete beam using Expanded Polystyrene bead (EPS) and Palm Oil Fuelled Ash (POFA). For EPS will replace with aggregate from 10.00 %, 20.00 %, and 30.00 %. While, for POFA will replace with cement in fixed value 20.00 % for each beam model not including beam control. The data of the material replacement for POFA and EPS have been taken from previous study. Then, using the ABAQUS software the solid concrete beam was created and they will be analyze to verify the performance mechanical properties concrete beam by compare the value of stress and strain in concrete. Besides that, we can analyzed the pattern of deformation concrete beam towards point load. The objective of this research has been achieve that ABAQUS can analyzed and verify the experimental result. The concrete beam containing POFA and EPS show that the stress and strain value for each specimen varied as a result of this study. When the percentage of POFA and EPS in concrete was greater, the value of stress strain in the concrete beam increases.

Keywords: POFA , EPS, ABAQUS, Solid Concrete Beam

1. Introduction

Concrete is an important building material in Malaysia that consists of three basic components including water, aggregates, and cement. Concrete use in civil engineering is vast, ranging from building bridges, dams, highways, and tall buildings. Compared to other traditional materials, high

*Corresponding author: mhairi@uthm.edu.my

concrete demand can be due to its high durability, strength, moldability and relative economy [1]. As in all common industrial factories, manufacturing of concrete beam results in the increasing content of CO_2 emission which is the main reason of the global warming. Then, the material to make concrete sustainable which is Expanded Polystyrene beads (EPS) and Palm Oil Fuel Ash (POFA). Expanded polystyrene beads (EPS) also can gave impact to ecosystem such as environment pollutions. This happen because millions of tons of waste EPS are not have enough space for landfilling, the costs for disposal this materials is considerable. Not only that, the production of palm oil fuel ash (POFA) also can make environment pollutions.

The weight of a concrete generally depends on the proportions of the mix and the partial ingredients. But typically a fresh concrete is heavy to lift because it consists of heavy materials that will harden when water is added to it. Extended polystyrene beads (EPS) replaced partial cement mixtures so that the concrete produced is of high compression strength and is lightweight which can be the ideal construction material to reduce the risk of earthquake damage to buildings. POFA contains siliceous compositions and reacted as pozzolans to produce a stronger and denser concrete [2].

1.1 Objective

This research was carried out for the production of lightweight concrete by focusing on replacement of the modified expanded polystyrene beads (EPS) as aggregate and the palm oil fuel ash (POFA). For this study, we use 20.00 % percentage of (POFA) and 10.00 %, 20.00 % and 30.00 % percentage for (EPS). The objectives of this study are:

1. To analyse concrete beam using ABAQUS software subjected to point load and flexural strength.
2. To analyse the performance of mechanical properties of concrete beam containing 0.00 %, 10.00 %, 20.00 %, and 30.00 % EPS and 20% POFA with simulation model
3. To compare the simulation results between normal concrete and concrete containing EPS and POFA using ABAQUS software

1.2 Scope of Study

The modeled concrete beam structure should include EPS and POFA as replacement material. ABAQUS is the program which will be used to test beam behaviour. The finite element using ABAQUS software approach is to evaluate the concrete beam and also to test the effects of the experiment in terms of deflection, stress and pattern of deformation. Experiment data from previous study have been taken to be used in ABAQUS software. The percentage of EPS is 10.00 %, 20.00 %, 30.00 % while POFA is permanent with 20.00 % has decided and shown in the Table 1 below.

Table 1: Percentage of EPS and POFA

Percentage of EPS (%)	Percentage of POFA (%)
0	20
10	20
20	20
30	20

2. Materials and Methods

This section will discuss and focus on the previous research, it shows that many attempts have been made in the construction industry to convert various waste in the production of concrete. Besides that, this section also will explain about material and method that were used in production of concrete.

2.1 Materials

2.1.1 Lighweight Concrete

Lightweight concrete has extreme importance to the construction industry. Most of current concrete research focuses on high-performance concrete, by which is meant a cost-effective material that satisfies demanding performance requirements, including lightweight concrete has been used widely due to its low density, superior thermal insulation properties compared to normal weight concrete. Lightweight concrete is 25.00 % to 30.00 % lighter than normal concrete which the structure. Previously, a study suggested for comparable strength normal weight concrete and lightweight concrete, the water penetration, depth of carbonation and chloride ion built-up in the lightweight concrete was higher than that in the corresponding normal weight concrete [3].

2.1.2 Expanded Polystyrene Beads (EPS)

Extended Polystyrene (EPS) is polystyrene in raw beads, which extended after it was heated by steam. EPS is light, has good characteristic energy absorption and good thermal insulator. EPS has been widely used to replace the normal aggregates because different size and arrangement of EPS can produce lightweight concrete with density lower than 1700 kg/m^3 [4]. EPS is chosen as a substitute material, which would reduce the weight of concrete equal to its density. Besides, EPS is also used for packaging and construction because it is lightweight, rigid, strong thermal insulation and high impact resistance [5].

There are several building or construction sites that are made from EPS performing different and significant functions. EPS is used in the design of works including large structures. For example, highways, bridges, rail lines, public buildings, or even residences with small families. The EPS features make it suitable for use as a lightweight filler, as an insulation, as an item for decorating or inventive touches, as a lightweight filling material in roads, to promote land drainage and so on.

2.1.3 Palm Oil Fuel Ash (POFA)

Palm oil industry plays a major role in the economic development of several tropical countries.Malaysia, Thailand and Indonesia are the biggest producers of palm oil and palm products in the world. It has been estimated that more than 8.1 million tons of total waste generated from this industry is produced in Malaysia [6]. From previous study and analysis on many different materials such as cement and aggregate replacement, such as palm oil fuel ash (POFA), pulverizing fuel ash (PFA) and many other fiber and pozzolanic materials shows the best results and can be used as cement substitute in limited quantities. POFA, it has been said as pozzolanic. It is Pozzolanic material between Class C and Class F as defined in ASTM C618-92a [7]. Because of its chemical properties POFA can be used as recycled materials for building. POFA constitutes about 5.00 % of the total waste materials after burning shells and fibers to generate electricity in palm oil mills.

Based on research by [2] it has been found that replacing POFA in concrete mixtures as binders will increase the rate of early strength and slows down at a later age. The cause of this matter is the content of calcium hydroxide from the hydration process which diminished in pozzolans through reaction with the composition of silica dioxides. The POFA particles were more porous and possessed a greater specific surface than that of cement and will cause densification of the pore structure due to the pozzolanic reactions [8].

2.1.4 ABAQUS

FEM is a good method for solving partial differential equations through complex domains. FEM is used in a wide variety of applications such as ANSYS, ABAQUS, and NASTRAN. ABAQUS software is used for the simulation of plain beam and RC beam behavior [9]. It used to solve complex engineering problems and applicable across industrial discipline such as mechanical engineering and civil engineering. Geometry model can be constructed before processed according to failure behavior criteria based on respective types of ABAQUS product [1]. The broad material modelling capability of ABAQUS makes it popular in the research institutions of engineering. In this study, the structural members are being analysed using ABAQUS for the modelling of solid concrete beam.

2.2 Methodology

2.2.1 Data Collection

The data for filling in this software was gathered from a previous study before using this software. Density for concrete, Young Modulus, Poisson ratio and design load ratio were the information collected. The dimension of all designed solid concrete beam is 150 mm wide x 150 mm deep x 500 mm long. Table 2 below shows the data of concrete properties for each type of beam which will be used in ABAQUS software [10].

Table 2: Concrete properties for each type of beam containing EPS and POFA

Percentage of EPS+POFA (%)	Dry Density (kg/m3)	Modulus of Elasticity, E_C (GPa)	Poisson Ratio
0% POFA 0%EPS	2380	26.67	0.203
20%POFA 0%EPS	2342	19.12	0.215
20%POFA 10%EPS	2235	17.17	0.229
20%POFA 20%EPS	2110	16.37	0.235
20%POFA 30%EPS	1994	14.19	0.266

2.2.2 Creating the model

First, create a file for the model and set work directory. Then click part by expanding the 'Model' tree in ABAQUS on the left panel and double-clicking the 'Parts' button. A box will pop up and write the name of the part at the box, modeling space, type and basic feature. Fill the name as ‘Beam’ and click “ok”. When drawing the part, it is recommended to start at the centroid (x0, y0) so that the coordinate will guide us to key-in the size of the part. The solid element has eight nodes with three degrees of freedom at each node which is x, y, and z directions. The necessary partitions of the concrete cylinder of size 500 mm × 150 x 150 mm are made to facilitate load application and meshing.

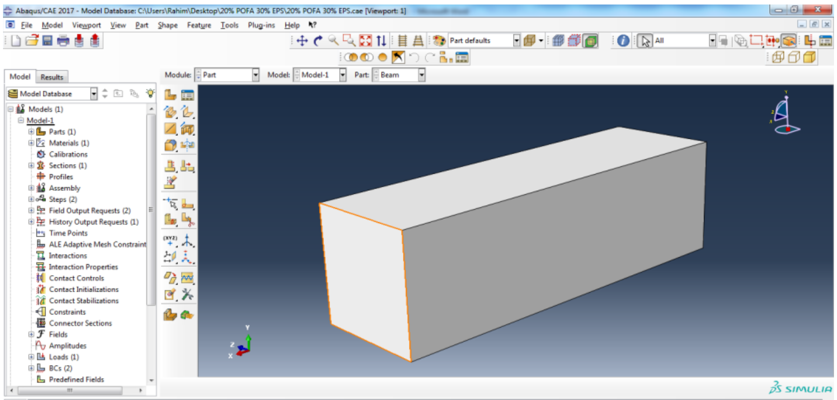

Figure 1: The model was created

2.2.3 Application of Material to the model

Under the 'Part 1' it will be option .Then go to 'Section Assignment' and click the button. After that, select the entire model cube to make sure whole cube are assigned. At the below will be present a name. Then rename the name as 'NormalConcrete'. After that, click done. Create Section table will pop up and select the 'Homogenous' and click continue. After that, the table of select material will pop up, and then select create. Young's Modulus and the Ratio value of Poisson was filled out. Similarly, EPS and POFA were created. This is where the data from the laboratory is used. The density, plasticity, young modulus, and any other properties can be added depends on the necessities.

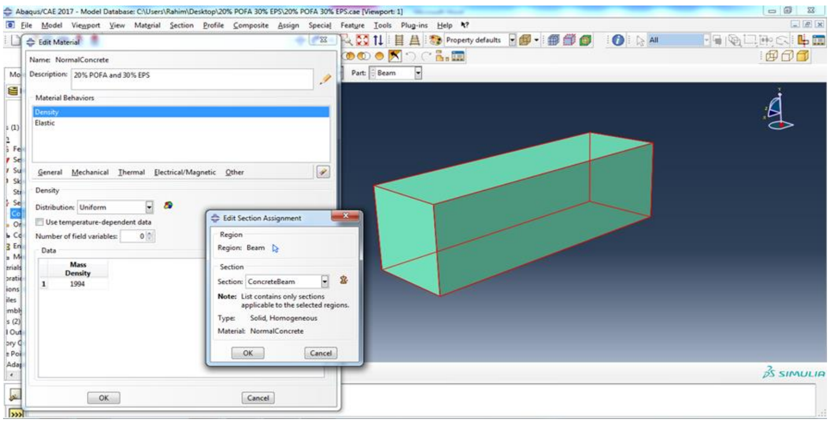

Figure 2: Assign the material in model

2.2.4 Meshing the model

Meshing is the process of generating nodes and elements. A mesh is generated by defining nodes and connecting them to define the elements. The mesh option is located under Parts section on the left side of the Abaqus interface. By clicking on the Seed Part, there will be option to key in the approximate global size where every amount entered will generate a node and becomes meshed after it is applied. The Mesh Part tool will be used to mesh the part of the structure and the size of the mesh can be changed later by using the Seed Part tool.

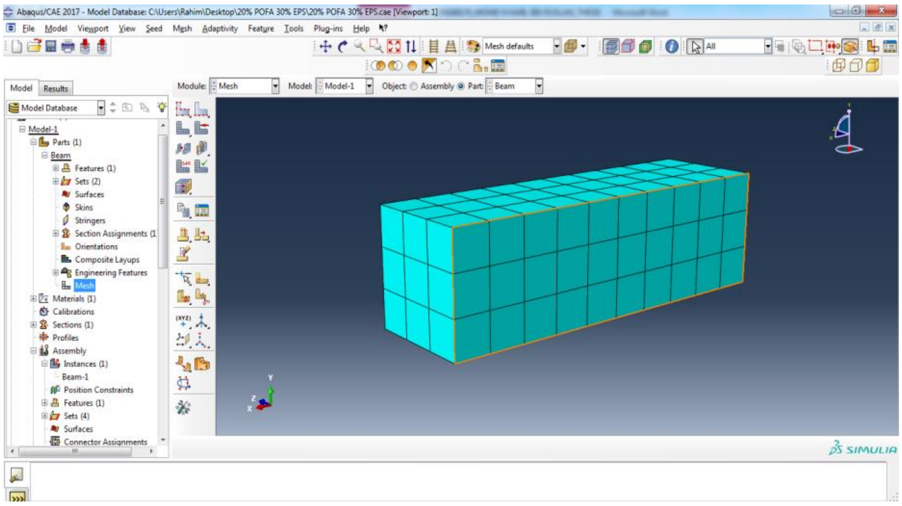

Figure 3: Mesh the concrete beam model

2.2.5 Step Module and Boundary Condition

The next part is "Step Module" which is located at the top of the toolbar. Select 'step' and click on create. In step, the current model can be edited or manipulated. In the new window box, change the setting to linear perturbation procedure type and static, linear perturbation and click Continue. Linear perturbation analysis provides linear response of the model.

Select the 'BC' located at the top of the toolbar and click on create. Then a 'create boundary condition' dialogue box will open and then change the settings to Initial - mechanical category – displacement/ rotation and then click continue. Select the region to apply BC. Displacement / rotation means holding the movement of selected nodes degree of freedom to 0. For fixed support, tick for U1 and U2. For roller support, tick for U2.

Next is "Load Module" which we will apply boundary condition and load to model frame. Boundary condition fixes the degree of freedom and has two types rotational and translational degree of freedom. Then click on create load, change the setting to Step-1, mechanical and concentrated force (applied to vertices) and click continue. Concentrated force is to the nodes. Now pick up the points to apply load. In this paper 30 kN is applied at top centre of the concrete model. After picking the points when you click done, another window will open this window will show the direction of the load that is CF2. We will use minus sign because load should be applied to opposite direction to the origin.

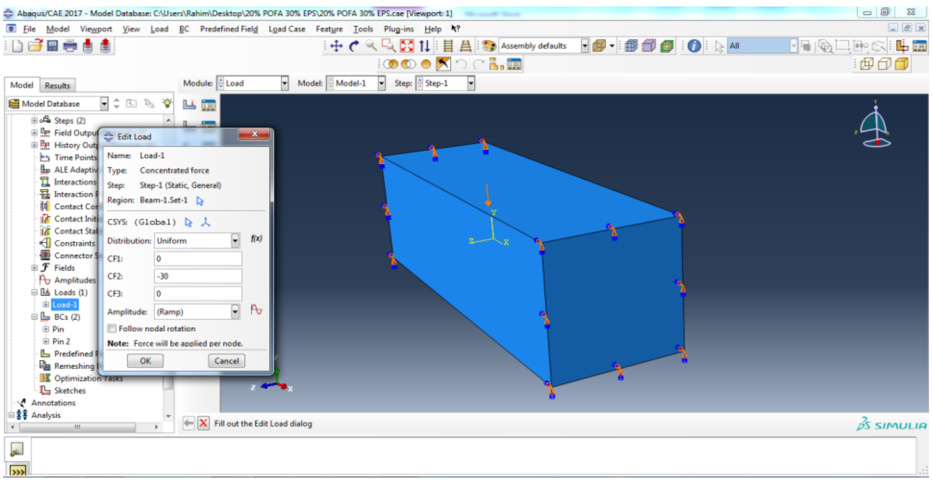

Figure 4: Point a Load and Boundary Conditions to model

2.2.6 Assign the Job to model

The model will be submitted for analysis and evaluation and get the results. select the Job located at the top and click on create. In this dialogue box, name the job and click continue and OK. Select 'job' again and click on manager and submit the job (model frame) for evaluation. Check for the command "completed successfully". Then click on results to view the results. Then click on report which is at the top and then click on field output. Give the location to save the 'abaqus.rpt', so that we can check the report. Results can also be viewed in visualisation module. Deformed shape, undeformed shape and contours can be viewed. The report can be generated by using the option field output, unique nodal. Click for stress component, displacements and reaction forces.

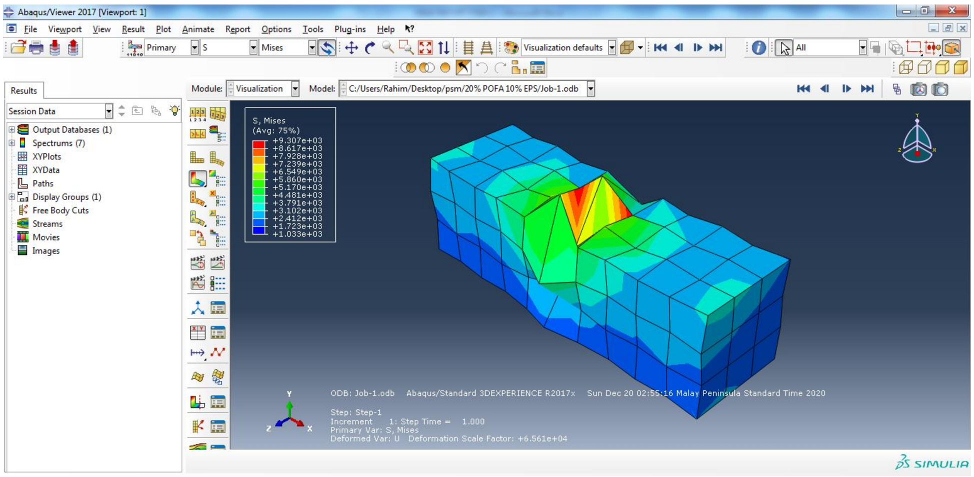

Figure 5: Applying Job to model

3. Result and Discussions

This chapter explains in more detail the findings and evaluation of a solid concrete beam using ABAQUS (FEM). 5 models are generated and meshed using this software and the data was gathered from ABAQUS software to get the result for stress, strain and deflection for each material that were replaced.

3.1 ABAQUS Data

3.1.1 Data analysis for deflection in concrete beam

The Figure 6 show the deformation for normal concrete beam. The deformation pattern is deflection of the concrete beam. The dark blue colour shows the minimum deflection reaction, while the red colour shows the highest deflection. The red colour is maximum stress and the blue minimum stress. Figure 7 show the deformation for 20.00 % POFA 0.00 % EPS concrete beam. The colour of the deflection and the deformation pattern of the beam is bit difference with normal concrete beam. Normal concrete beam has the red and the orange colour compare to others. That proves that normal concrete is more deflection compared other beam model. When 20.00 % POFA replaced in the beam, the colour at the point load changes to yellow, so we can concluded the value of stress is decreased. Then, the Figure 8 is containing 30.00 % of EPS has no significance difference in deformation pattern but have difference with normal concrete and 20.00 % POFA 0.00 % EPS

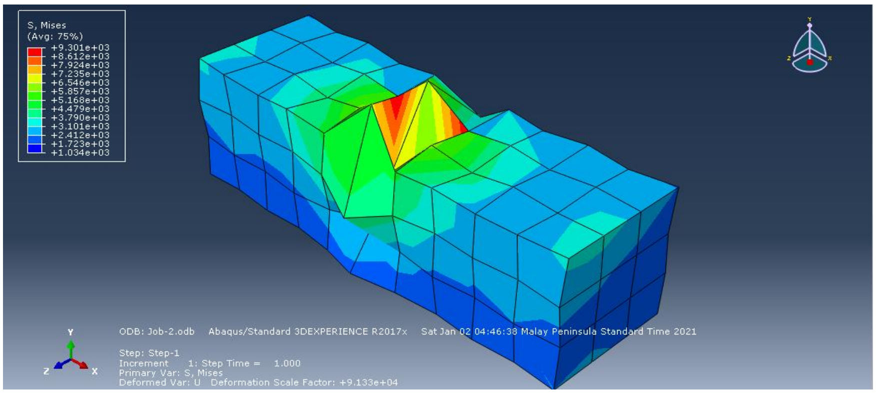

Figure 6: The deformation pattern for normal concrete beam

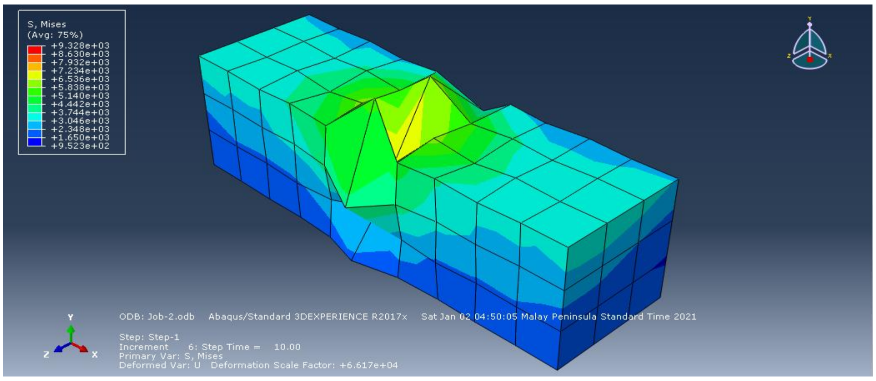

Figure 7: The deformation pattern for concrete beam containing 20.00 % POFA and 0.00 % EPS

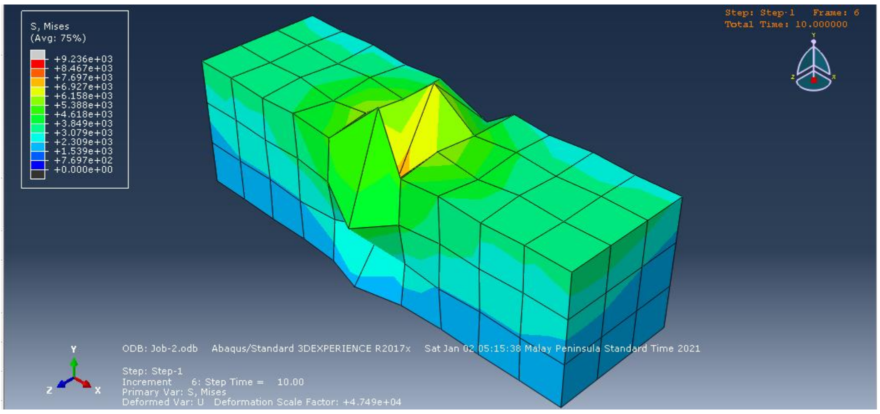

Figure 8: The deformation pattern for concrete beam containing 20.00 % POFA and 30.00 % EPS

3.1.2 The relationship of Stress and Strain on concrete beam

The Figure 9 shows the highest value stress and strain at the 20.00 % POFA 30.00 % EPS specimen. Next, difference between normal concrete and others specimen that can see the value of stress and strain increased for each specimen. The value of strain increased when the replacement material which is 20.00 % POFA and 10.00 %, 20.00 % , 30.00 % EPS was added. It shows that, the replacement of POFA and EPS will improve the performance of concrete. The slope for the for the graf more inclined towards strain when the replacement material was added. When the slope of graf strain and stress increased together, we can concluded the beam is in good performance. For the conclusion, the higher the percentage of POFA and EPS used as the replacement material, the higher the stress strain value of the concrete beam and performance of the concrete beam increase. However, the concrete mixes should not exceed 25.00 % to 50.00 % to ensure the good performance of lightweight concrete containing EPS and POFA according the previous study [8].

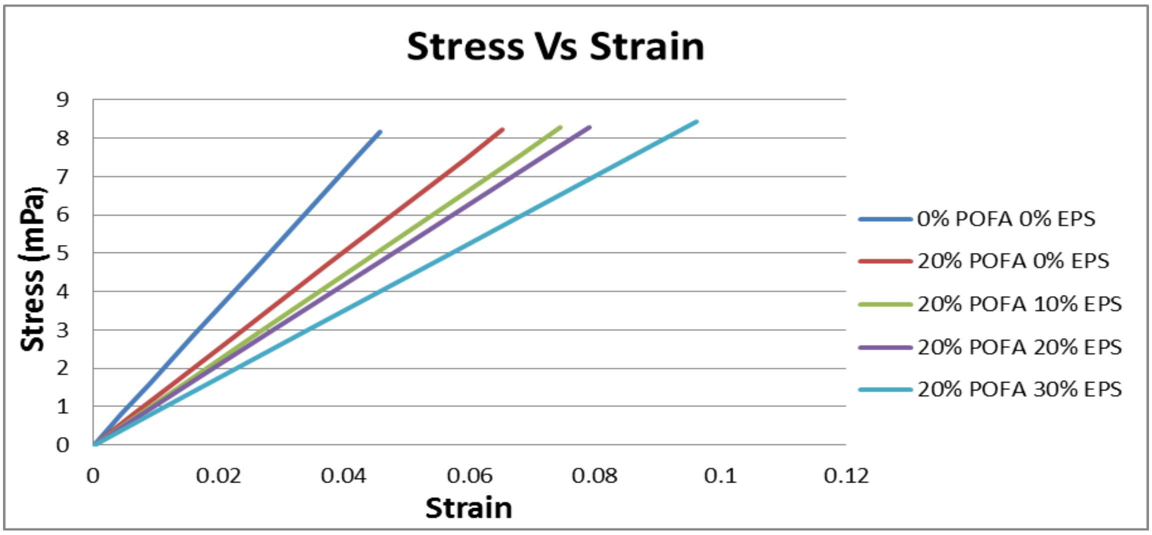

Figure 9: The graph of Stress vs Strain for concrete beam model

Table 3: the value of highest stress and strain

Specimen	Strain	Stress (mPa)
0%POFA0%EPS	0.046	8.17
20%POFA0%EPS	0.065	8.21
20%POFA10%EPS	0.075	8.27
20%POFA20%EPS	0.079	8.30
20%POFA30%EPS	0.096	8.42

3.1.3 Data Analysis for the Stress and density of the concrete beam

Figure 10 show the graph of stress of the solid concrete beam over density. From the graph, each point has represented the value of concrete beam containing EPS and POFA. The highest value stress point is 8.42 mPa and 1994 kg/m^3 density is for 20.00 % POFA and 30.00 % EPS. The lowest value of stress is 8.17 and 2380 kg/m^3 density for 0.00 %, 0.00 % EPS (control). According to the data, the density of concrete beam decreased when the value of replacement for EPS increased but the value of stress is increased. The characteristic of EPS is less water absorption. Then, when the EPS applied in each sample, the beads distributed in the concrete beam and will be increased the voids and minimize the density of concrete beam. In addition, because of pore refinement, the use of POFA decreases the pore sizes in lightweight concrete and give the optimum strength to concrete beam.[8]

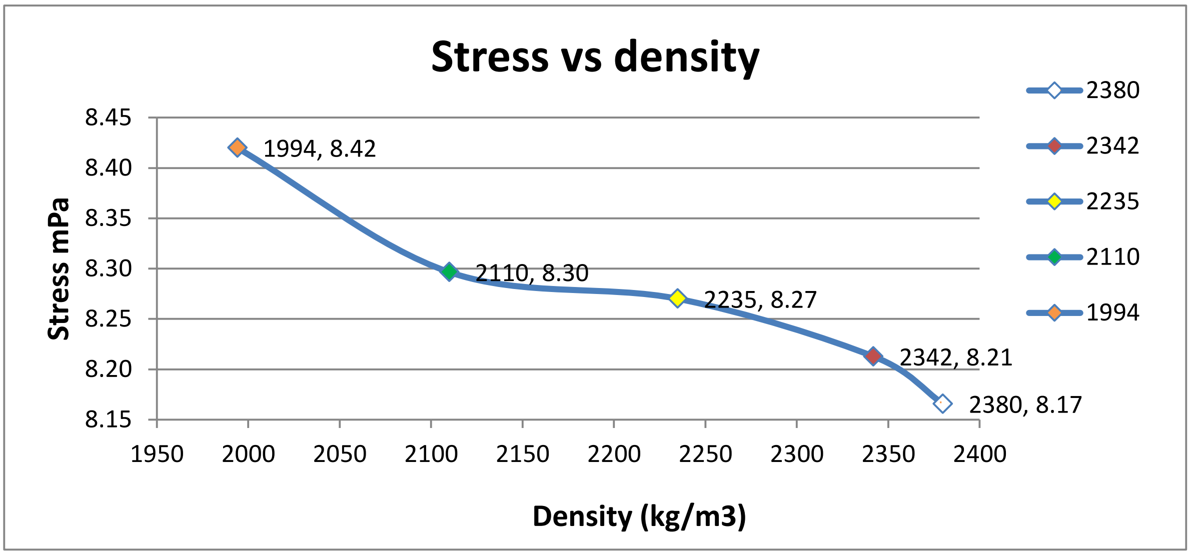

Figure 10: The graph of Stress against Density for concrete beam model

Table 4: the value of stress and density

Specimen	Density (kg/m^3)	Stress (mPa)
0%POFA0%EPS	2380	8.17
20%POFA0%EPS	2342	8.21
20%POFA10%EPS	2235	8.27
20%POFA20%EPS	2110	8.30
20%POFA30%EPS	1994	8.42

4. Conclusion

As a conclusion, through this research the use Palm Oil Fuel Ash (POFA) as replacement cement and Modified EPS as replacement fine aggregates can be analyses using Abaqus, finite element method. The conclusion can be summarized as follows:

i. ABAQUS can analyze the concrete cube and can verify the experimental work result. Then, the first objective was achieved.

ii. The second objective about performances of mechanical properties of concrete that containing 20.00 % of POFA and 0.00 %, 10.00 %, 20.00 % and 30.00 % of EPS with simulation model by using finite element method that is ABAQUS based on previous experimental can be verify.

iii. The last objective was to compare the behaviour results between normal concrete and concrete containing EPS and POFA using ABAQUS software. From the analysis shows that, the higher the percentage of POFA and EPS in concrete beam, the highest the value of the stress and strain. However, the concrete mixes should not exceed 25.00 % to 50.00 % to ensure the good performance of lightweight concrete containing EPS and POFA.

iv. The analysis shows that, the highest the percentage of POFA and EPS, the higher the strength of concrete and the lower its density. The characteristic of EPS is less water absorption. Then, when the EPS applied in each sample, the beads distributed in the concrete beam and will be increased the voids and minimize the density of concrete beam. In addition, because of pore refinement, the use of POFA decreases the pore sizes in lightweight concrete and give the optimum strength to concrete beam.

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