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Mechanical Properties of Concrete Containing POFA and EPS as Replacement Materials

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Abstract: To solve the problems of increase in amount of the oil palm waste and expanded polystyrene, high emission of carbon dioxide and high density or normal concrete, a research of replacing cement and fine aggregate with expanded polystyrene (EPS) and palm oil fuel ash (POFA) were done. Few cylinders concrete with 150 mm diameter and 300 mm height were created using Simulia Abaqus CAE. These cylinders concrete was set with different materials which are 0.00 % POFA with 10.00 % to 30.00 % EPS, 10.00 % POFA with 0.00 % to 30.00 % EPS and 20.00 % POFA with 0.00 % to 30.00 % EPS. The main purpose of this study was to determine the mechanical properties of concrete containing EPS and POFA as replacement materials, determine the optimum percentage of EPS and POFA as the replacement materials in concrete and determine the maximum stress for concrete with 20.00 % POFA and 30.00 % EPS. From this paper, concluded that optimum percentage of POFA is 20.00 % while EPS is 30.00 % as replacement materials in concrete.

Keywords: Concrete, POFA, EPS, Abaqus

1. Introduction

Nowadays, globalization led to technology risen rapidly in most of all industry exist. Researcher compete to each other trying to generate new ideas of development to improve adjacent industry. Development of technology also contributes in increasing waste from industry. To minimize the volume of waste generated, people start to used it in industry and create new things from it. This study is a research on improvement of concrete using waste materials, control the high emission of carbon dioxide from concrete and produce low density concrete with high strength.

In this research, cement and aggregate have been replaced with EPS and POFA in order to increase the strength of concrete. Cement has a role as binding agent once it mixed with water and aggregate. Ordinary Portland cement is the commonly cement used in Malaysia. Fine aggregate has role to fill in void between coarse aggregate. It increases the strength of the concrete as it minimizes the void between the coarse aggregate.

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1.1 Problem Statement

Usually, wastes increased parallel with the growth of technologies. Malaysia is a tropical country and suitable for cultivated oil crops [1]. And nowadays, reported by The Malaysia Palm Oil Council (MPOC), oil palm cultivation used almost 4.49 million hectares of land in Malaysia and produce about 17.73 million tonnes of palm oil and 2.13 tonnes of palm kernel oil. Palm oil industry give the highest waste as oil palm is the main crops in Malaysia.

Construction industry was listed as anti-environment industry. This is because the main material in construction which is concrete were recognized as materials that emitted large amount of CO_2 during the construction process [2]. Normally, developer tends to use high strength concrete (HSC) but HSC release more carbon dioxide compares to normal strength concrete [3].

Normal concrete has high density. High density concrete has high thermal conductivity, high shrinkage and low heat resistance. High density concrete difficult to reduce dead load, slower the building load and have high haulage cost [4].

In the same time, existing lightweight concrete has lower strength compared with conventional lightweight [5]. To overcome this problem, invention of lightweight concrete with the replacement of fine aggregate with EPS and replacement of cement with POFA were introduced.

1.2 Objectives

The study was conducted to do an improvement on concrete. POFA and EPS were used in producing concrete with environmentally friendly. The main objectives of this project are:

- To determine the mechanical properties of concrete containing EPS and POFA as replacement materials.
- To determine the optimum percentage of EPS and POFA as the replacement materials in concrete.
- To determine the maximum stress for concrete with 20% POFA and 30% EPS.

1.3 Scope of Study

This study was to investigate on mechanical properties of concrete with EPS and POFA as replacement materials. In this study, the fine aggregate and cement was replaced by EPS and POFA as shown below.

Table 1: Percentage of POFA and EPS used

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

The mechanical properties of concrete consisting EPS and POFA as the replacement materials were determine using the Simulia Abaqus CAE Software. The stress and strain on the concrete were obtain in order to know the strength of the concrete. The performance of the concrete with EPS and POFA replacement was then compared with the ordinary concrete. As the results, the optimum percentage of replacement of EPS and POFA were determined.

2. Literature Review

2.1 Polystyrene

Polystyrene is a synthetic aromatic polymer with molecular formula of ((C8H8)n) and consist of styrene monomer. It can be in solid or liquid form. Due to it high molecular weight, polystyrene have poor barrier to oxygen and water vapour and effect from it, polystyrene have low melting point **[6].** Polystyrene are nonbiodegradable because it has durable thermoplastic. Polystyrene undergoes biodegradation but the rate of biodegradation is very low which is less than 1.00 % of polystyrene can be degrading by fungi and microbes withing 90 days [6].

EPS is a polystyrene in raw bead that had been heated and become expand because of the heat provided. According to [7], EPS is a lightweight cellular plastics material consisting of fine spherical shaped particles. EPS is a good thermal insulator and was used in application of precast roof, lightweight infill block and wall panel. Even though EPS is a material with low strength, but it has good energy absorbing characteristics. An EPS bead consist of 2.00 % raw material and 98.00 % of air, which chemically composed of two elements which are carbon and hydrogen [8].

2.2 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is by product obtained by burning of palm oil fibers, empty fruit bunches and shells as fuel in palm oil mill boilers [9]. Usually, about 85.00 % fibers, 15.00 % shells and empty fruit bunches are burned in boiler under temperature of about 900-1000 °C to produce energy for extracting process of crude palm oil. POFA is an excellent pozzolanic material and can be used as an alternative cement replacement in concrete.

POFA has specific gravity 40.00 % lower than ordinary Portland cement which the value of the specific gravity is around 1.78 to 1.97. The specific gravity of the POFA related with the POFA particle size. POFA with finer particle size has higher specific gravity of POFA because porosity decrease with the reduction of particle size.

3. Methodology

The method used to achieve the objective of this study will be clearly described. Several model of cylinder concrete specimens with different replacement ratio of EPS and POFA were prepared using Abaqus CAE software.

3.1 Methodology Flow Chart

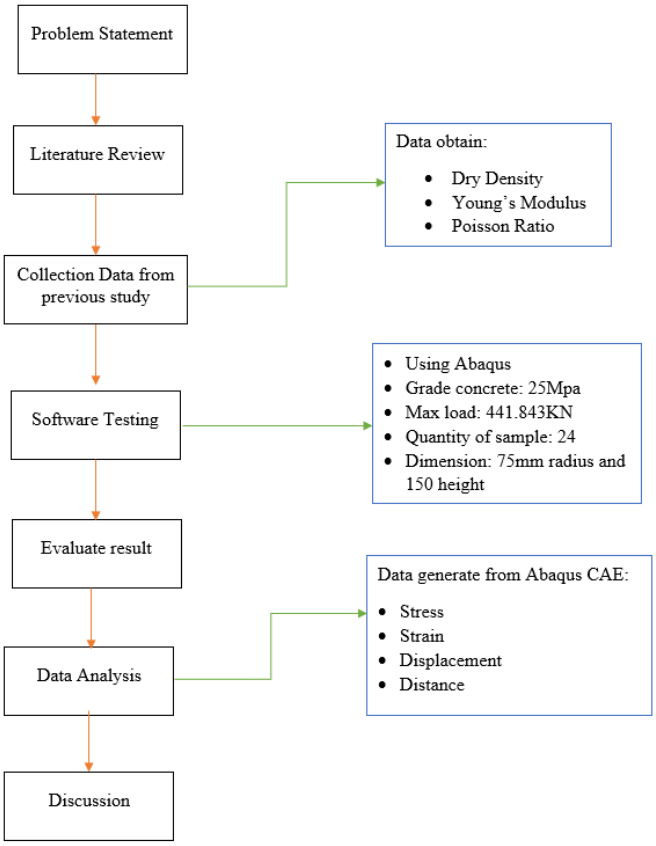

Figure 1: Flowchart of study

3.3 Work Procedure

3.3.1 Preparation of model

A 3D cylinder with radius 75mm and depth 300 were created. The type is deformable and the shape is solid. A 3D load shell also had been created with radius 80 mm and 40 mm depth. This load shell is set as discrete rigid type. This load shell has a cut with dimension 20 mm depth and 75 mm radius.

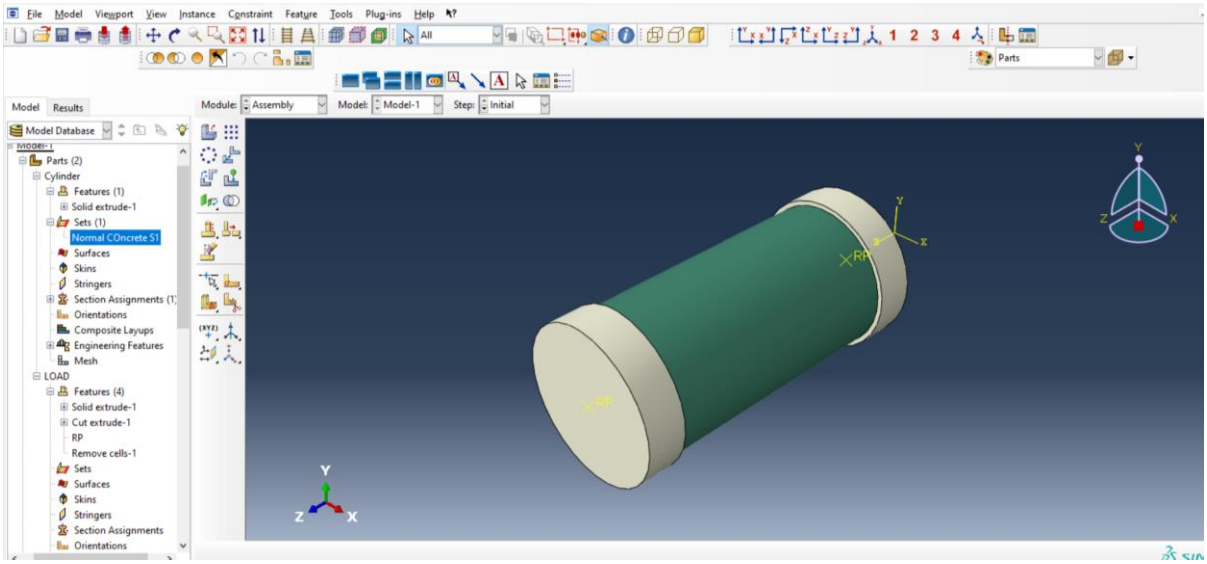

Figure 2: Cylinder concrete model

3.3.2 Applying type of materials to model

The materials of model were specified based on the dry density, Young's Modulus and Poisson Ration. This specification of specimens is based on previous study [10].

Table 2: Specification of Specimens

Percentage of POFA and EPS	Dry Density (kg/m^3)	Modulus Young, E (Mpa)		Poisson Ratio, v	
		Sample 1	Sample 2	Sample 1	Sample 2
0.00 %POFA and 0.00 %EPS (Normal Concrete)	2380	31227	25520	-0.205	-0.201
0.00 %POFA and 10.00 %EPS	2260	24717	21981	-0.214	-0.211
0.00 %POFA and 20.00 %EPS	2140	20212	18240	-0.2123	-0.2224
0.00 %POFA and 30.00 %EPS	2025	15862	13938	-0.235	-0.235
10.00 %POFA and 0.00 %EPS	2355	25694	24398	-0.211	-0.206
10.00 %POFA and 10.00 %EPS	2248	20533	18605	-0.219	-0.22
10.00 %POFA and 20.00 %EPS	2126	18175	21418	-0.233	-0.234
10.00 %POFA and 30.00 %EPS	2011	14222	18148	-0.241	-0.243
20.00 %POFA and 0.00 %EPS	2342	19110	19133	-0.214	-0.215
20.00 %POFA and 10.00 %EPS	2235	17006	15409	-0.228	-0.229
20.00 %POFA and 20.00 %EPS	2110	14683	17952	-0.239	-0.231
20.00 %POFA and 30.00 %EPS	1994	14639	13840	-0.265	-0.266

3.3.3 Applying the assembly to the model

Create instance for both cylinder and load shell part. Make sure the instance was mesh on point. Without this instance, the next step of methodology cannot be applied

3.3.4 Applying the step to the model

After creating instance, continue with step. Make sure the procedure type for the step is general and static. On the NLGeom and choose automatic stabilization. Set the type of incrementation as automatic, maximum number of increments is 100, increment size for initial is 0.1, minimum incrementation is 1E-005 and maximum is 1.

3.3.5 Applying the interaction

Create the interaction property. Choose penalty for friction formulation under tangential behavior. Set the directionally as isotropic and key in the friction coefficient as 0.2. Next, create interaction and set the type of selected surface as general contact (standard).

3.3.6 Applying the load and boundary condition to the model

Create boundary condition. Categorized it as mechanical and the type for the selected step as symmetry/antisymmetry/encastre then continue and click the bottom of the model then click done for

the region of boundary condition. Edit boundary condition by choosing encastre (U1= U2= U3= UR1= UR2= UR3= 0) for CSYS (Global).

Create new load, name the load as load-1 and categorized the load as mechanical, the type for selected step as pressure. Apply the load created on the upper surface of the cylinder. Set the distribution to uniform, magnitude to 441.843 kN and amplitude to (Ramp)

3.3.7 Applying mesh to the model

Mesh the part with approximate global size 1.5. For the first step, mesh the cylinder first then continue with the load shell. Make sure the curvature control is ticked and set the maximum deviation factor as 0.1. Tick by global fraction of global size as 0.1

3.3.8 Assigning job to the model

Create job and name job as compression. Make sure the source of the job is model which is both cylinder and load shell. Choose the model and continue the job procedure by choosing the job type as full analysis, run mode as background and submit time immediately. After clicking ok, submit the job created.

4. Results and Discussion

From the model diameter 150 mm and depth 300 mm created in Abaqus CAE, analysis on that model were done. Different materials of model were set from 0.00 % POFA to 20.00 % POFA and from 0.00 % EPS to 30.00 % EPS. Dry density, Young's Modulus and Poisson Ratio for each model were set. Data generated for the model are strass, strain, and distance. The result of different percentage of POFA and EPS are compared. POFA can enhancing the concrete properties to resist chloride attack, assisting to increase the drying shrinkage of concrete, decreasing heat development, resisting concrete sulphate attack and reducing the effect of acidic environment on concrete. Other than that, high fineness of POFA particle strength the concrete as it can fill the void between the others particle [11].

4.1 Discussions

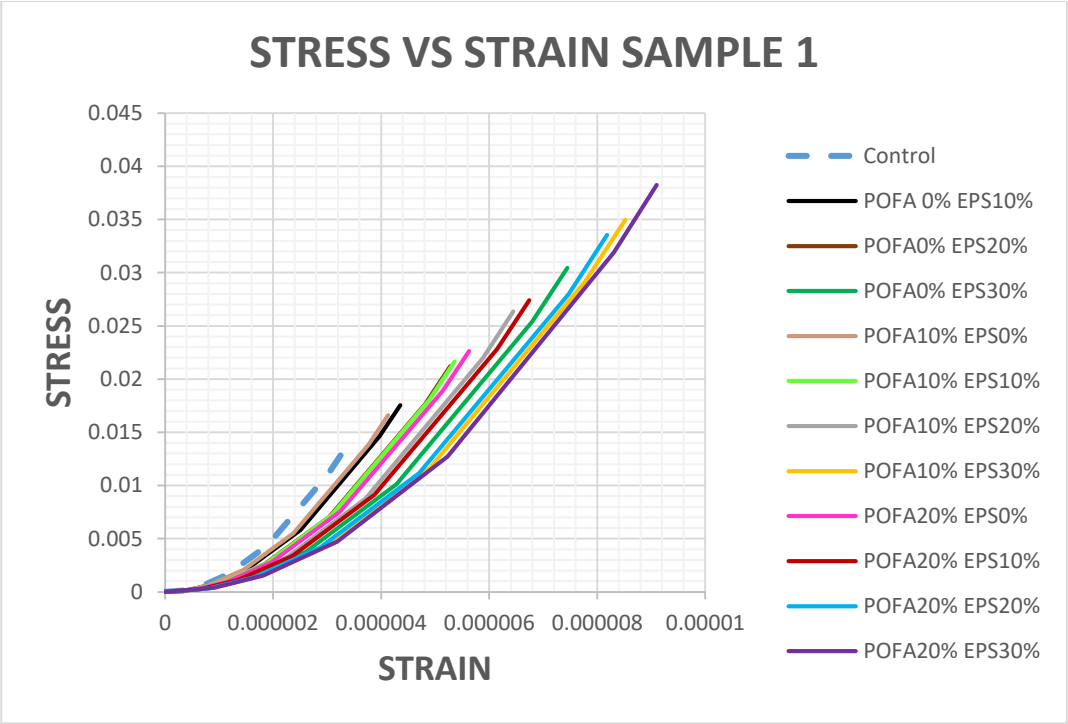

Figure 3: Graph stress vs strain for sample 1

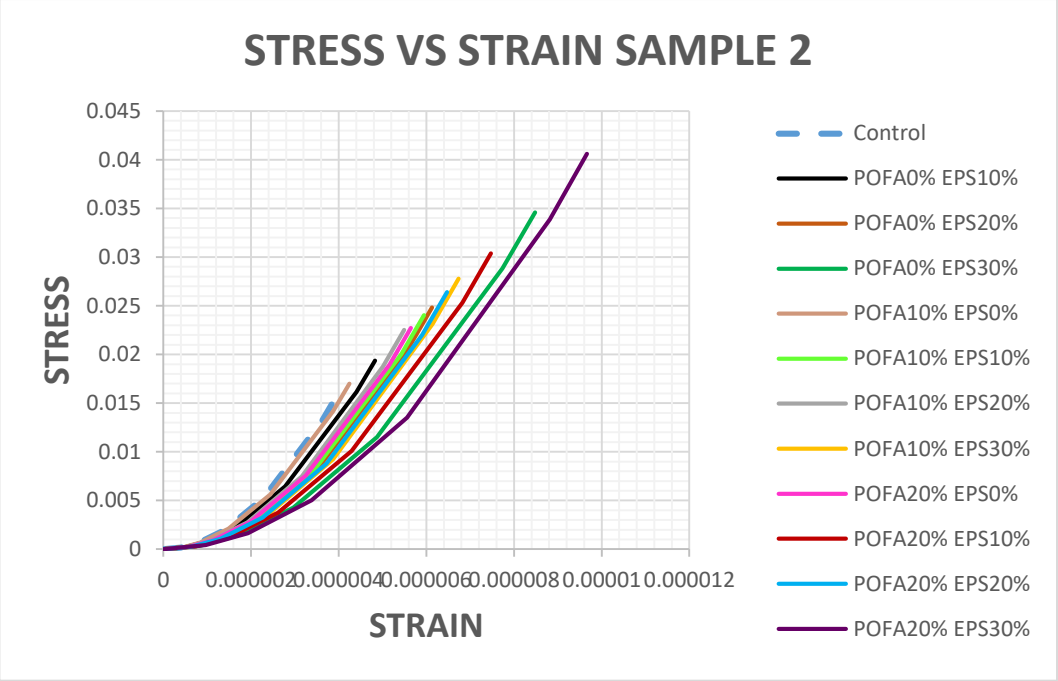

Figure 4: Graph stress vs strain for sample 2

Stress vs strain graph represent the strength of the concrete itself. The higher the gradient of the slope, the more flexible and brittle the concrete. Referring to both graph of strain vs stress from sample one and sample two, we can conclude that, the concrete with 20 percent POFA and 30 percent EPS as replacement material in concrete mixture is the optimum percent in producing high strength concrete.

Comparing the research made by Hamada, Jokhio, Yahaya, Humada and Gul in 2018, they conducted a research in improving concrete with POFA. They conclude that the optimum percent of POFA that improve the concrete strength is 10.00 % to 20.00 %. Data from this project was parallel with the conclusion made by them [12].

POFA with particle size less than 100 nm has better characteristics than normal cement mortar as filler and binder in cement mortar. Finer POFA can reduce air void in concrete. Thus, higher compressive strength of concrete created. The water absorption increases as the percentage of POFA increase. But then, with the presence of EPS, water absorption decrease as EPS is a non-absorbent material. So, the conclusion is, the higher the percentage of replacement materials, the lower the density of the concrete, the optimum the water absorption and also minimizing carbon dioxide gas emissions and thus improving environmental conditions [12].

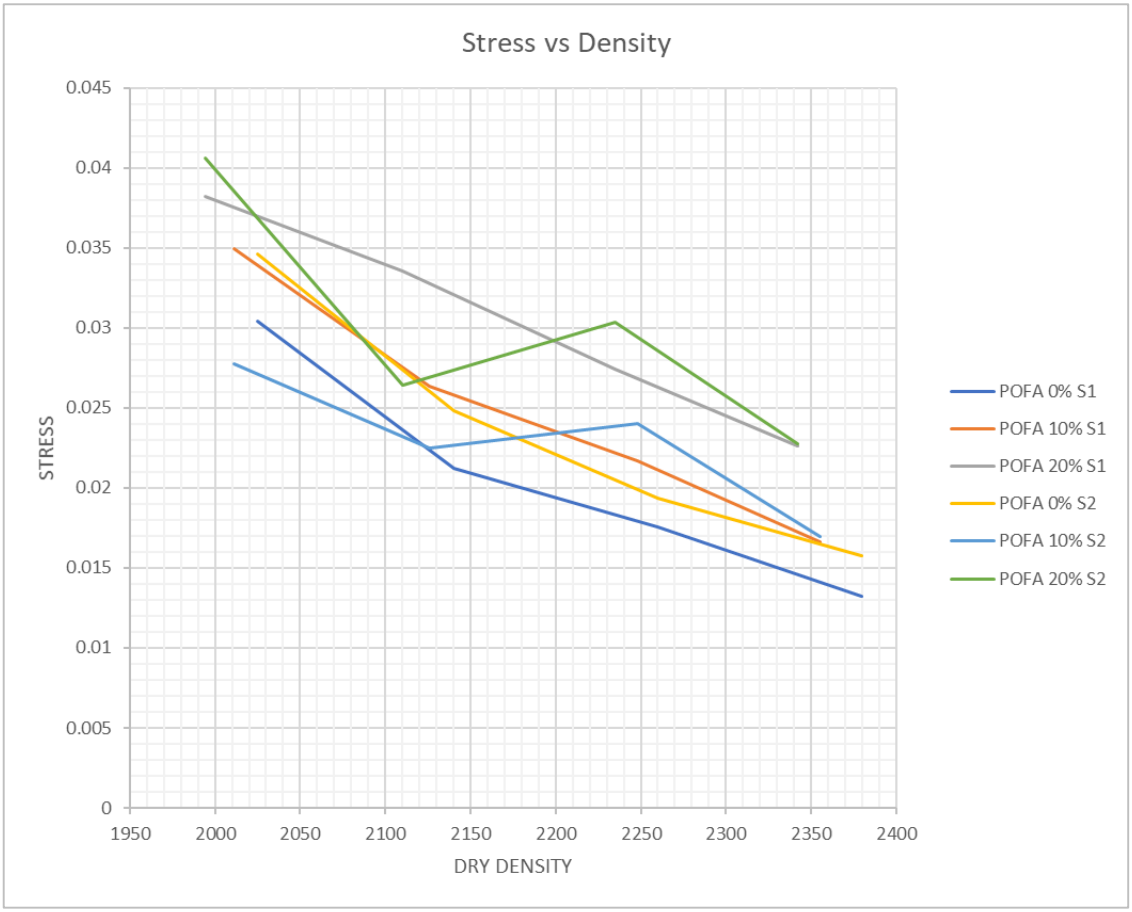

Figure 5: Graph stress vs dry density

From graph obtain, low density concrete with the mix of POFA and EPS as replacement materials can increase the strength of concrete. The fineness of POFA is related to its micro filling ability that fills micro-voids between cement particles and eventually contributes to an increase in the compressive strength. Finer particles have higher surface area, which affects the pozzolanic activity and enhance the compressive strength [13].

5. Conclusion and Recommendation

In conclusion, the cylinder concrete models are analyzed using the Simulia Abaqus CAE software with their respective material behavior and properties. The results of the analysis are analyzed based on the performance of the models in terms of deformation, stress, and strain. Based on the analysis, the following conclusions are made:

i. The cylinder concrete model containing 20.00 % POFA and 30.00 % EPS is the optimum percentage for concrete in order to produce high strength concrete
ii. Concrete with the mixture of 20.00 % POFA and 30.00 % EPS have is more flexible and brittle
iii. A pattern in the performance indicates the maximum load and minimum load can withstand by the model. Concrete mixture of 20.00 % POFA and 30.00 % EPS have the highest red colour and thus showing that, it is the strongest compare to other
iv. This research used 441.843 kN load which is equal to 25 MPa grade concrete. Maximum stress for concrete grade 25 for concrete with 20.00 % POFA and 30.00 % EPS as the replacement material is $0.91 Nm^{-2}$
v. Decrease in Young's Modulus also effect the strength of concrete. Sample 1 have higher Young's Modulus compare to sample 2. Sample 1 is stronger than sample 2.

In order to get best result, improvement need to be done. Below listed few of recommendations for improving the results:

i. Make at least 3 sample. From the samples made, fine the average to make sure the data obtain is the best data. Other than that, various sample made have more aspect to compare in order to measure the strength of concrete.
ii. Compare the result obtain from the software with result obtain from the lab test. This is to ensure there is no mistakes were done during both procedure
iii. Use more than one software and comparing the data from all of the software. From this recommendation, accurate data from the best software can be obtain. Other than that, use various software to generate all of the mechanical properties of concrete containing EPS and POFA as replacement materials.
iv. Do a similar research with different range of percentage of EPS and POFA. Increase the percent of POFA up from 25% until 50% and percentage of EPS from 35% until 60%. From that research, conclude excessive POFA and EPS either can create high strength concrete or low strength of concrete.

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