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Finite Element Analysis on Cube and Cylinder Model of Ceramic Waste Concrete

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Abstract: Ceramic industry is considered to produce a massive volume of ceramic waste per year, and most of it is found in landfills. The reuse of such wastes in concrete may be a win-win scenario. This paper focuses on the adaptation of ceramic waste as the partial replacement as a coarse aggregate in concrete mixture. This study is to determine performance of concrete compression behaviour whether the waste material that replace natural coarse aggregates are performed to compare with the ordinary concrete. The proportion of the replacement material in this study was 0.00 %, 20.00 %, 40.00 % and 60.00 %. There are two model created in this study, which are concrete cube and concrete cylinder, with size of specimen concrete cube 150 mm x 150 mm x 150 mm while concrete cylinder 0.15 m x 0.30 m. Data from previous study was used such as concrete density, modulus elasticity and Poisson ratio to assign in Finite Element Model. This result is to indicate the stress and strain and also deformation of displacement of concrete mix with ceramic waste and the strength of concrete that increased with the addition of ceramic waste, compared to the conventional concrete strength. The result from the Abaqus simulation states that ceramic waste concrete at 40.00 % produces the best performance of compressive strength.

Keywords: Ceramic Waste, Cube and Cylinder, Compression Test, Abaqus Simulation, Finite Element Model

1. Introduction

Concrete is one of the most significant components used in construction work. Whereas it is a combination of coarse aggregates, fine aggregates and a cement binder. Such materials are combined with sufficient amounts of water, accompanied by a hydration from chemical reaction leading to a very solid and stable concrete components or frameworks [1]. However, concrete manufacturing will lead to various causes of environmental issues, such as harm to ecosystem by mining of products, use of considerable amounts of energy for extraction, processing and transport of cement. While concrete comprises just 9.00 -13.00 % of cement, the production of concrete used 92.00 % of the energy for its

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manufacture. Cement dust includes free silica particles, lime and fragments of chromium, all of which may have a detrimental impact on the health of workers and the environment [2,3].

Removing and reusing waste has been one of the most critical issues in the world. A significant amount of waste is generated annually in all countries [4]. Any of such products are nor reused or, whether they are treated, contribute to energy wastage and contamination, which in effect raise the danger to the ecosystem of such resources [5]. In this study, ceramics waste has been chosen to replace the conventional coarse aggregate in the mixture of concrete. Tile and positive ceramics are among the materials most widely utilized in buildings. Concrete is the primary component element of several structures. Conduct of the concrete is non-linear and full in complexity. Increased use of computer-based design and simulation methods have also boosted the need for an accurate solution to the problems. This leads to problems in simulating and modelling concrete structures. A successful solution has been choosing for this project is to use the general intent of the ABAQUS finite element program [6,7]. The objectives of this research are: (1) to develop model series of cube and cylinder compressive strength of ceramic waste concrete, (2) to analyse behaviour of stress-strain in cube and cylinder model of ceramic waste concrete and (3) to analyse behaviour of displacement in cube and cylinder model of ceramic waste concrete.

2. Concrete

Concrete, in the broadest context, is any substance or material created through applying of a cement media. In general, this approach is the result of a reaction between hydraulic cement and water. These days, though, only several descriptions will include a broad variety of products: concrete is made of many varieties of cement and often includes pozzolan, fly ash, blast furnace slag, microsilica, chemicals, recycled concrete aggregates, blends, polymers, fibres and so on; and such concretes may be dried, steam-cured, vacuum-treated, hydraulically shaped, shock-vibrated, extruded. The presence of cement, water, fine and coarse aggregate, and admixtures will produce what so called a mixture between these materials [8,9].

According to Neville & Brooks in their book of 'Concrete as A Structural Material', there are three reasons on why these materials being used. First, because of the cementing medium, such as cement hydration goods, may be seen as an integral construction material, with the aggregate playing the function of a good or better diluent. Second, coarse aggregate can be seen as a minimasonry which is joined together by mortar. As for the third is, for first approximation, concrete consists of two phases: (1) hydrated cement paste and (2) aggregate. As a consequence, the concrete attributes are controlled by the features of the two phases and also by the existence of confrontation between them [9-11].

2.1 High Strength Concrete

The methods and technology for producing High Strength Concrete (HSC) are not basically different from those required for concrete of normal grade except that the emphasis on quality control is perhaps greater with HSC. HSC can be produced with all of the cements and cement replacements normally available in Singapore, including Portland cement, sulfate-resisting Portland cement, and combinations with pulverised fuel ash and ground granulated blast furnace, silica fume slag. High early strength cements should preferably be avoided as a rapid rise in hydration temperature may cause problems of (internal) cracks or micro-cracks due to the higher cementitious material content. HSC can be produced with a wide range of aggregates, but smooth and/or rounded aggregates may tend to exhibit aggregate bond failure at a relatively low strength. Crushed rock aggregates, of 10 to 20 mm size, which are not too angular and elongated, should preferably be used. However, it has been found that bond strength between smaller size aggregates is greater than between larger size aggregates and for that reason smaller size aggregates (say 10 to 17 mm) tend to give better results. Fine sands should be avoided, particularly those with high absorption. Superplasticisers should be used to achieve maximum water reduction, although plasticisers may be adequate for lower strength HSC (C60 to C70).

Silica fume (microsilica) can be used to enhance the strength at high levels. To facilitate handling, silica fume is often blended into a slurry with superplasticisers or supplied as a densified powder. The basic proportioning of an HSC mix follows the same method as for normal strength concrete, with the objective of producing a cohesive mix with minimum voids. This can be done by theoretical calculations or subjective laboratory trials. The basic strength to water/cement ratio relationships used for producing normal strength concrete are equally valid when applied to HSC, except that the target water/cement ratio can be in the range 0.30-0.35 or even lower. It is essential to ensure full compaction at these levels. A higher ultimate strength can be obtained by designing a mix with a low initial strength gain and cementitious additions. This is partially due to avoidance of micro-cracking associated with high thermal gradients. This effect can be facilitated if strength compliance is measured at 56 instead of 28 days. Increasing the cement content may not always produce higher strength. Above certain levels it may have little effect. An optimum amount of total cementitious material usually appears to be between 450 and 550 kg/m^3. HSC mixes tend to be very cohesive and a concrete with a measured slump of 50 mm may be difficult to place. As HSC is likely to be used in heavily reinforced sections, a higher workability, should be specified if honeycombing is to be avoided. When superplasticisers are used, concrete tends to lose workability rapidly. HSC containing such materials must therefore be transported, placed and finished before they lose their effect. Many modern superplasticisers can retain reasonable workability for a period of about 100 minutes, but care is still needed, particularly on projects where ready-mixed concrete delivery trucks have long journey times. Often, in order to avoid drastic decreases in slump and resultant difficulty in placing, superplasticisers are only partly mixed on batching, the balance being added on site prior to pouring [12].

2.2 Green Concrete

Since the severe problem of CO^2 pollution is being debated, it is proposed that the building industry use green concrete. Green concrete is characterized as a concrete that uses waste material that has at least one of its components will not result to the degradation of the ecosystem or has a good value and a sustainable life cycle. Numerous reports also explored realistic solutions that might minimize high energy used and environmental effects, such as combining high percentage cement with fly ash, the usage of renewable pozzolans and ceramic waste. Cleaner techniques are used in concrete manufacturing to improve efficiency in class of strength, stiffness and longevity [13-15].

Green Concrete, as its name implies, is environmentally friendly and protect the world by utilizing waste products created by factories in different ways, such as rice husk ash, ceramic waste, etc., to create concrete frameworks that conserve energy [16]. The use of it helps to save energy through less emissions. Green concrete is also inexpensive to manufacture, there are various advantages of practicing green concrete in construction industry. Application of green concrete is known as a good way to minimize environment pollution and increase the durability of concrete. Green concrete is also often unexpensive to manufacture, because waste materials are used as a partial replacement for cement or fully replacement for coarse aggregates, waste management charges are reduced, electricity usage in construction is lower and longevity is improved [17].

2.3 Ceramic Wastes

Waste issue of the ceramic industry and the usage of non-renewable materials such as cement and aggregates and eliminating environmental issues associated with land-filled waste, contributing to a more productive concrete market. Studies indicate that the mixtures of concrete by using ceramic as aggregates perform better than control mixtures of respect to compressive strength, capillary water absorption, oxygen permeability and chloride diffusion resulting in a more durable structure [18,19]. Ceramic waste is preferred to substitute the traditional coarse aggregate in a concrete mixture in order to popular the environmental challenges now emerging. The use of ceramic waste as building products has given numerous advantages, such as the potential to provide good elastic durability. Strong resilience under compressive loads, outstanding chemical tolerance and high temperature stability. It is also noted that ceramics, as a replacement for the coarse aggregate, may have improved mechanical conduct compared to traditional coarse aggregates [20].

2.3.1 Previous Study on Application of Ceramic Waste Concrete

Usage of ceramic wastes as the partial replacement of coarse aggregate in concrete has produces a lot of benefits on the mechanical properties of concrete compared to the conventional concrete that used natural stone as its coarse aggregate. First study states that concrete with ceramic wastes as aggregate has higher compressive strength and modulus elasticity compared to the normal concrete [12]. Besides that, research study state that the maximum compressive strength they obtained from the application of ceramic wastes in concrete is at 5.00 % replacement [21]. A study states that ceramic waste aggregate will produce a good quality of concrete. The highest compressive strength obtained in the 75.00 % replacement of coarse aggregate in concrete Modulus elasticity of ceramic wastes concrete also reduces along with the increasing of its replacement [22]. Also mentioned that the best production of ceramic waste concrete is on the 40.00 % replacement of coarse aggregate [23]. Lastly, research study states that the highest compressive strength of ceramic waste concrete is on the 10.00 % partial replacement of coarse aggregate [24].

Table 1: Shows the effect to mechanical properties of concrete when using ceramic waste in its aggregate

No.	Journals	Testing Applied	Mechanical properties of ceramic wastes concrete
1	Green high strength concrete containing recycled waste ceramic aggregates and waste carpet fibres: Mechanical, durability and microstructural properties [12].	• Compressive Strength Test • Stress-strain relationship • Modulus elasticity	Ceramic waste concrete: • Has greater compressive strength and modulus elasticity, compare to normal concrete.
2	Mechanical properties of concrete produced from partial replacement with ceramic tile wastes [21].	• Compressive Strength Test • Tensile Strength Test	Ceramic waste concrete: • Maximum compressive strength obtained at 5% replacement.
3	Eco-efficient concrete containing recycled ceramic wastes aggregate [22].	• Density • Workability • Compressive Strength Test • Modulus of Elasticity	• Ceramic waste aggregate concrete achieved good quality concrete. • 75% replacement of coarse aggregate achieved the highest concrete strength. • Modulus elasticity decreases with the increasing of ceramic waste aggregate.
4	Partial replacement of coarse aggregate with broken ceramic tiles in concrete production [23].	• Density • Workability • Compressive Strength Test	• Replacement of 40% coarse aggregate can be used in concrete production.
5	Study of mechanical properties of lightweight aggregate concrete by using pumice stone, ceramic tiles and clc lightweight bricks [24].	• Density • Compressive Strength Test • Flexural Strength Test	• Compressive strength of 10% ceramic tiles replacement recorded the highest compare to conventional concrete.

2.4 Simulation of Abaqus Software

Concrete is a stone-like artificial material used in numerous building structures. It is quite relatively inexpensive and strong, essential to stability in any structure. It's also very simple to create and very flexible to use by moulded it into your preferred shapes. it has the ability to withstand massive load force with a combination of various element to enhance its potential and compression strength. to indicate a compression strength, the idea of the concrete cube specimen is provided to act as the majority of the characteristic of the concrete-based structure. The average strength of the concrete is between 15 MPa (2200 psi) and 30 MPa (4400 psi), higher in commercial and industrial systems.

In order to obtain more compression strength data, a stimulation of the Finite Element Analysis (FEA) is provided. A software such as ABAQUS are to be deployed to gain more efficient and solid prove that the concrete specimen is safe to be utilized. The Finite Element Analysis (FEA) is numerical method used to solve engineering problem using an array of mathematical techniques. This analysis implemented a mathematical procedure called the Finite Element System (FEM) of a certain Physical Phenomenon. The method subdivided a larger problem into smaller simpler part that are known as finite element.

3. Methodology

Methodology flowchart of this study as shown in Figure 1, was prepared to give an insight of the current sequences of the overall activities that was carried out from the preliminary stage to the implementation stage where all the result data collected from previous study and the final result of cube and cylinder model produced from Abaqus Software (version 6.14).

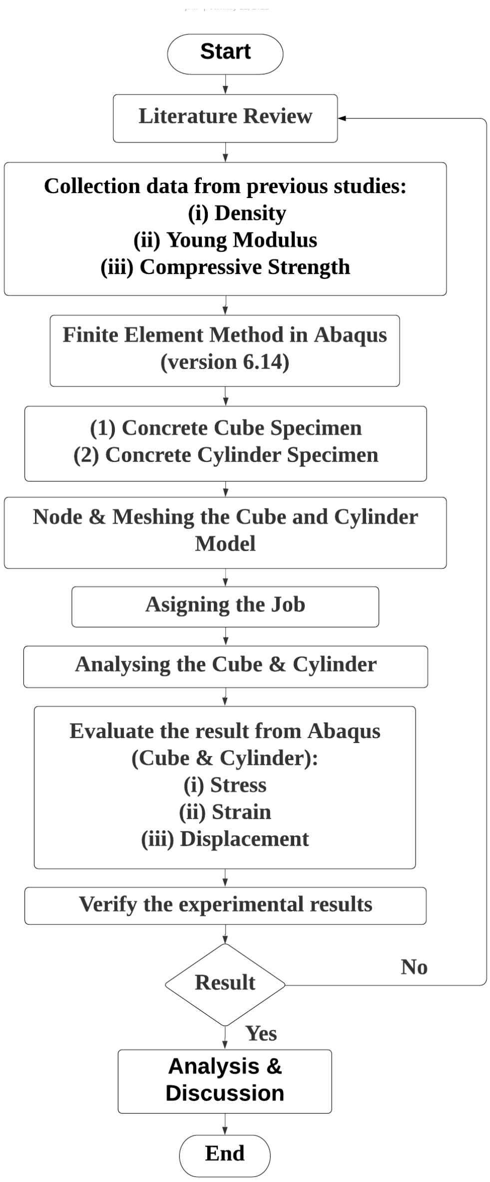


Figure 1: Methodology of the flowchart

3.1 Parameter of Experimental Assigning to Abaqus Model

According to previous study, waste ceramic aggregate has been used to conduct an investigation in high strength concrete (HSC), with different partial replacement of coarse aggregates in concrete mixes, 20.00 %, 40.00 % and 60.00 %. With regard to the hardened concrete, replacing 40.00 % of natural coarse aggregate led to the increase in modulus elasticity and compressive strength of ceramic waste concrete. The data in this journal has been chosen to be among the reliable increase in data of ceramic waste concrete, hence can be applied in the Abaqus model [12].

Table 2: Density, modulus elasticity & compressive strength [12]

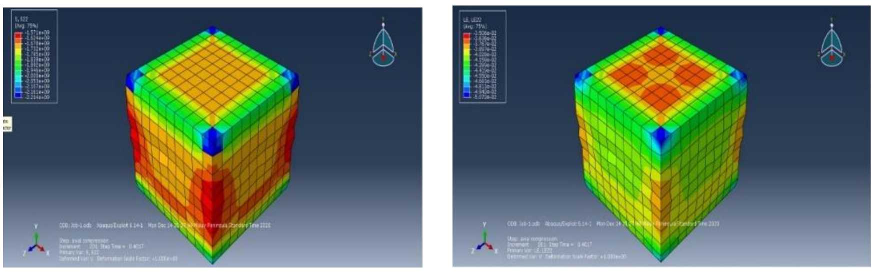
Mix Designation	w/c	CCA (%)	Density of concrete (Kg/m^3)	Modulus elasticity (GPa)	Compressive strength (MPa)
High Strength Concrete	0.37	0	2576	41.6	75.9
	0.37	20	2562	41.9	77.3
	0.37	40	2554	42.8	80.5
	0.37	60	2550	42.1	78.1

4. Results and Findings

Results and findings obtained from the data of Finite Element Method (FEM) Abaqus software. The 4-model specimen for both of concrete cube and concrete cylinder was created and meshed in Abaqus with partial replacement of 0.00 %, 20.00 %, 40.00 % and 60.00 %. The analyses result of concrete cube and concrete cylinder that containing each percentage of ceramic wastes and normal concrete were discussed through the displacement, stress and strain graphs.

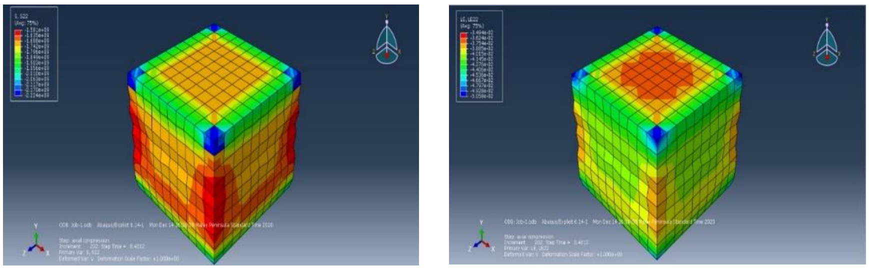
4.1 Stress and Strain Deformation Model (Cube Concrete Specimen)

The deformation on the cube specimen for the stress it can be described as stresses either tensile or compressive. The variable parameter for the materials is chosen by their ability to resist compressive forces, depending upon the application. For instance, concrete is strong in compression and relatively weak in tension. Steel is equally strong in both tension and compression. Besides that, strain defined as the change in the length of its original shape as to compared with after any fusion of different variation in the materials. The deformation of strains in the concrete cube are the reduction in volume of cube concrete model after the application of loading which change the volume with respect to volume of concrete before applied loading. In Figure 2, 3, 4, and 5 below, showed four (4) types of colour, which are blue, green, yellow and red. (1) Blue colour for minimum stress or strain level area on the concrete cubes, (2) both of green and yellow colours is for medium stress or strain level area on the concrete cubes. (3) Red colour is for maximum stress or strain level area happened because of stress or strain dispersion on concrete cubes from above load.



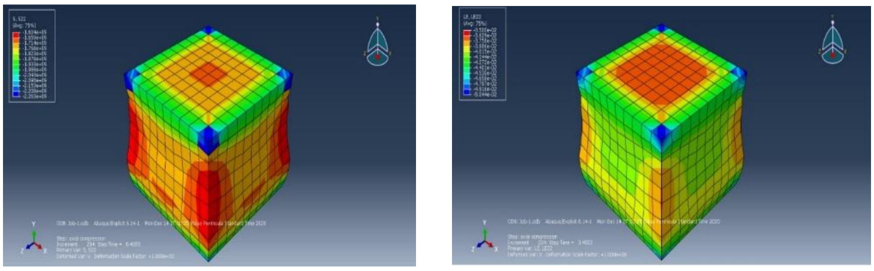
(a) (b)

Figure 2 (a): Stress Deformation for Normal Concrete (0%), (b): Strain Deformation for Normal Concrete (0%)



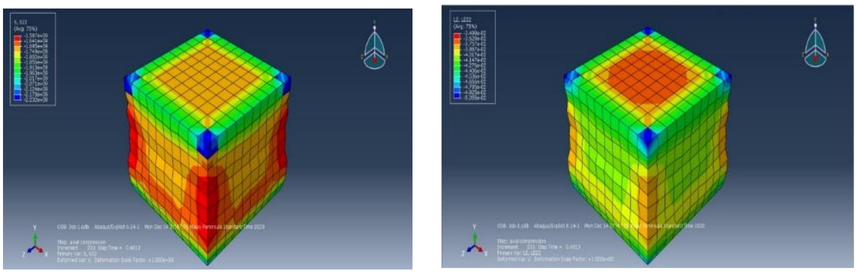
(a) (b)

Figure 3 (a): Stress Deformation for Normal Concrete (20%), (b): Strain Deformation for Normal Concrete (20%)



(a) (b)

Figure 4 (a): Stress Deformation for Normal Concrete (40%), (b): Strain Deformation for Normal Concrete (40%)



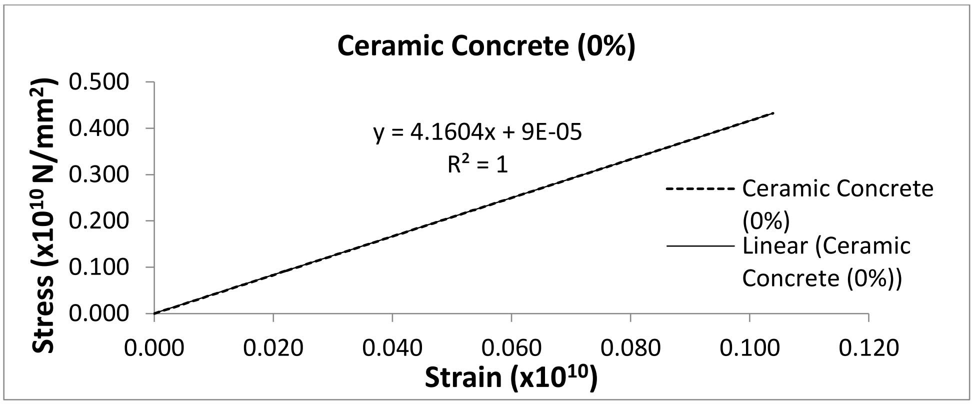
(a) (b)

Figure 5 (a): Stress Deformation for Normal Concrete (60%), (b): Strain Deformation for Normal Concrete (60%)

4.1.2 Stress vs Strain Deformation Graph (Cube Concrete Specimen)

The tabulation of the slope for the stress versus strain graph are contributed by the variable data result of the young modulus where the stress versus strain curvature in the elastic region are defined as the elastic modulus, E. The Concrete Cube Specimen should be designed so that any applied load would not cause the stress in the structure to be greater than yield stress of the material. Below in **Figure 6** are the stress versus strain of all the proportions ranging from 0.00 % to 60.00 %.

From Figure 6 below, the value of R^2 recorded the same for all ceramic concrete proportions, with value $R^2 = 1$. The linear equation of normal concrete was y = 4.1604x + 9E-05, while ceramic concrete cube of 20.00 % recorded linear equation as y = 4.1905x + 9E-05, ceramic concrete cube of 40.00 % recorded y = 4.2804x + 1E-04 and ceramic concrete cube of 60.00 % was y = 4.2105x + 9E-05. All the ceramic concrete resulted in difference value as each concrete contained different amount of ceramic concrete. A lot of parameters that is missing in order to complete the simulation such as concrete damage plasticity, compressive and tensile behaviour such as yield stress, inelastic and also the cracking strain of concrete cubes. All those reasons lead to the incomplete output of concrete cube models as it was hard for Abaqus to run analysis with only few parameters, this will produce minimum differences of displacement between concrete cube models.



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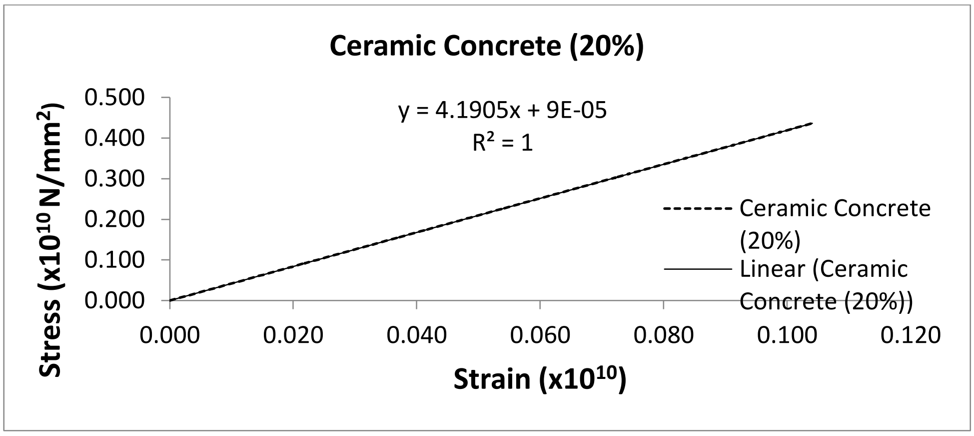

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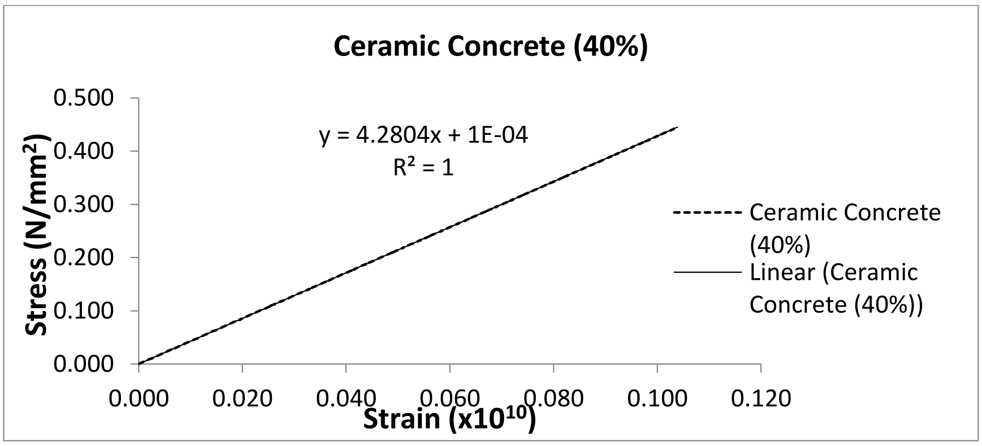

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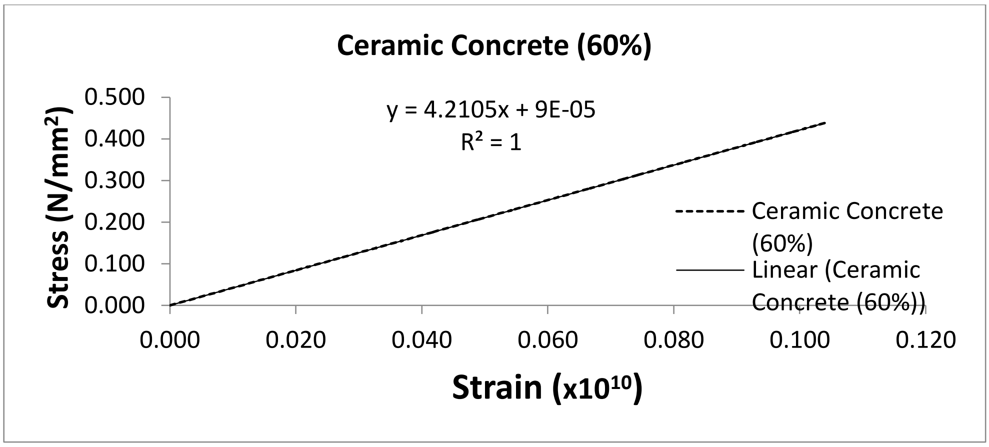


(d)

Figure 6 (a): Graph of stress against strain for normal concrete cube model, (b) Graph of stress against strain for ceramic concrete cube model (20%), (c) Graph of stress against strain for ceramic concrete cube model (40%) and (d) Graph of stress against strain for ceramic concrete cube model (60%)

Figure 7 shows that there was slightly difference between stress values for all ceramic waste concrete. By comparing all the graphs, ceramic concrete of 40.00 % recorded maximum value of gradient with 4.2804. The maximum value of gradient referring to highest stress value or peak stress. The slopier the graph, the highest the stress value would be, and best choice for concrete in refrain high value of load. It can be concluded that the stress strain of cube models recorded the same pattern with previous study. Previous study stated that the highest compressive strength was on 40.00 % partial replacement of ceramic waste aggregate in concrete mixture [37].

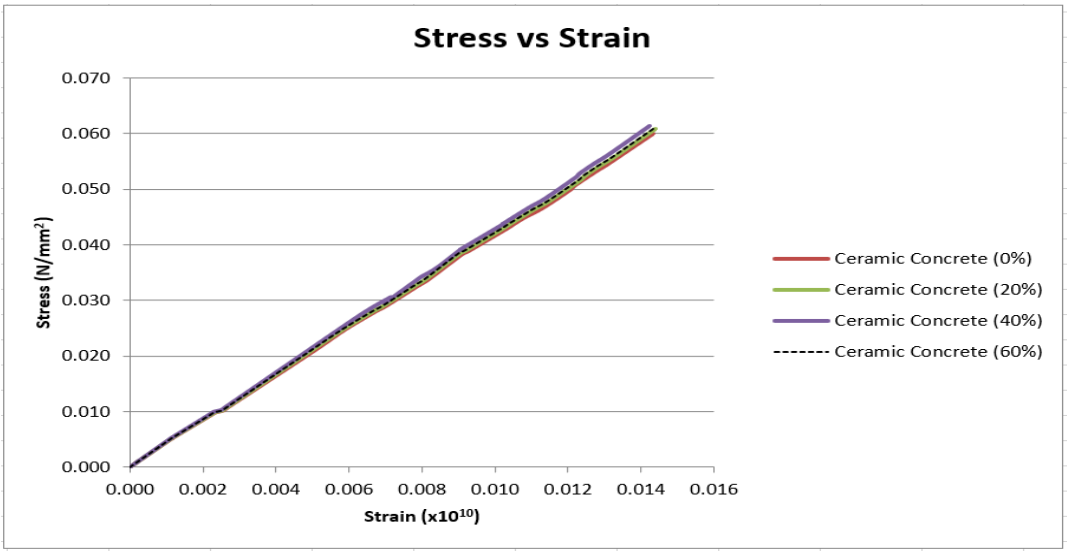
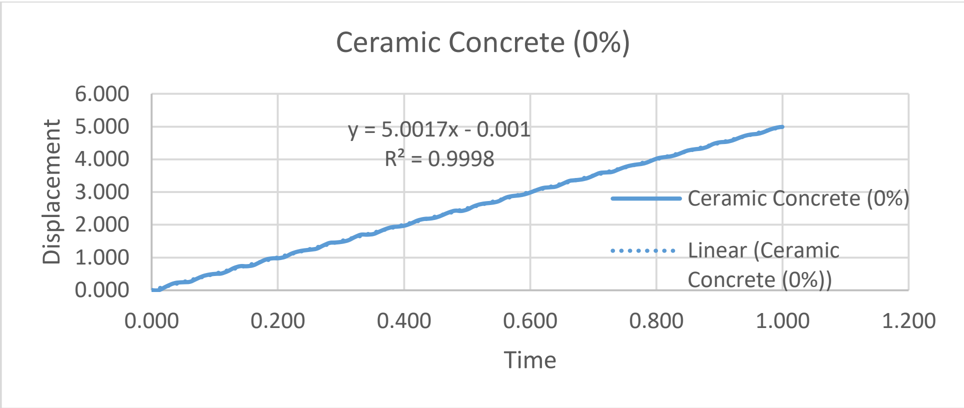


Figure 7: Graph of stress against strain for all the cube models

4.2 Displacement vs Time Deformation Graph (Cube Concrete Specimen)

A displacement-time graph shows on how the displacement of a moving object changes with time. A sloping line on a displacement-time graph shows that the object is moving. Hence, this scenario is just the same to the concrete properties. If the displacement-time graph produced a sloping line, means that the concrete properties is moving when load is applied on it.

From Figure 8 below, the value of R^2 recorded the same for all ceramic concrete proportions, with value R^2 = 0.998. The linear equation of normal concrete was y = 5.0017x - 0.001, while ceramic concrete cube of 20.00 % recorded linear equation as y = 5.0016x - 0.0008, ceramic concrete cube of 40.00 % recorded y = 5.0008x - 0.0009 and ceramic concrete cube of 60.00 % was y = 5.0016x - 0.0012. All the ceramic concrete resulted in difference value as each concrete contained different amount of ceramic concrete.



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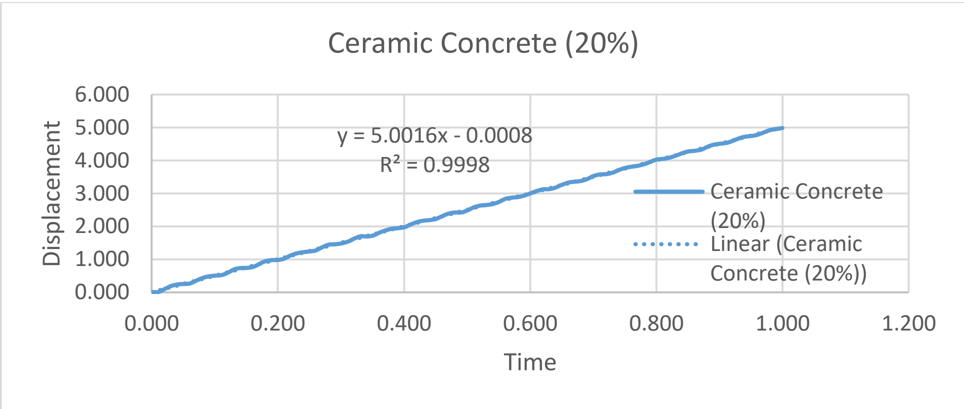

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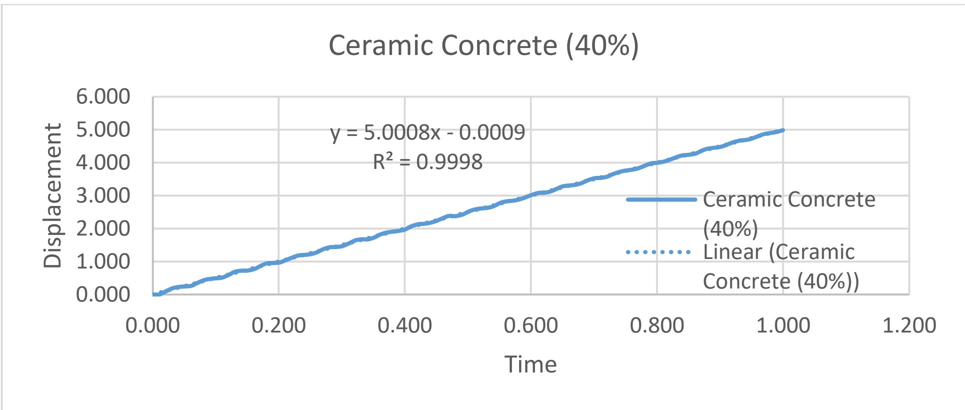

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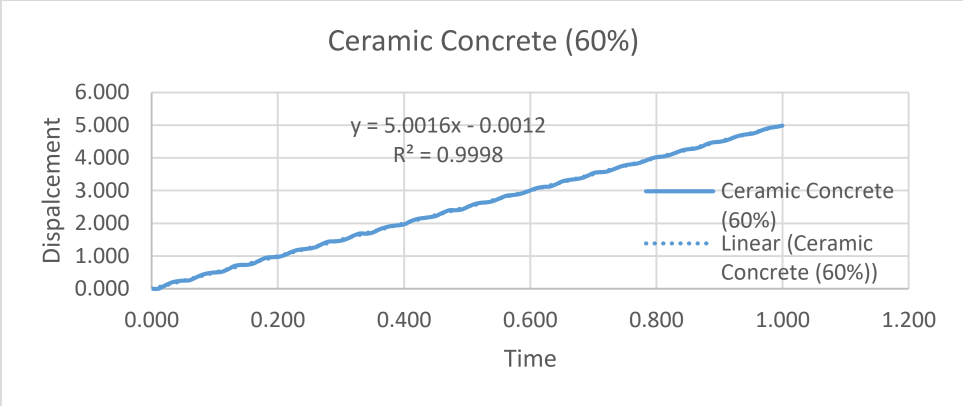


(d)

Figure 8 (a): Graph of displacement against time for normal concrete cube model, (b) Graph of displacement against time for ceramic concrete cube model (20%) (c) Graph displacement against time for ceramic concrete cube model (40%) and (d) Graph displacement against time for ceramic concrete cube model (60%)

Figure 9 shows that there was slightly difference between stress values for all ceramic waste concrete. By comparing all the graphs, ceramic concrete of 40.00 % recorded minimum value of gradient with 5.0008. The minimum value of gradient referring to lowest strain value. The lowest the gradient of graph, the lowest the strain value would be, and best choice for concrete in refrain high value of load. It can be concluded that the displacement of cube models recorded the same pattern with previous study. Previous study stated that the highest compressive strength was on 40.00 % partial replacement of ceramic waste aggregate in concrete mixture [37].

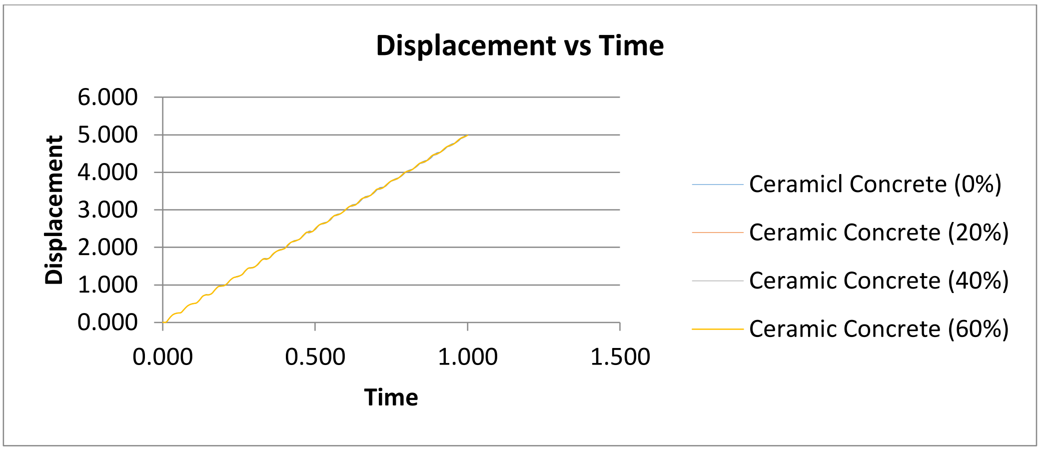
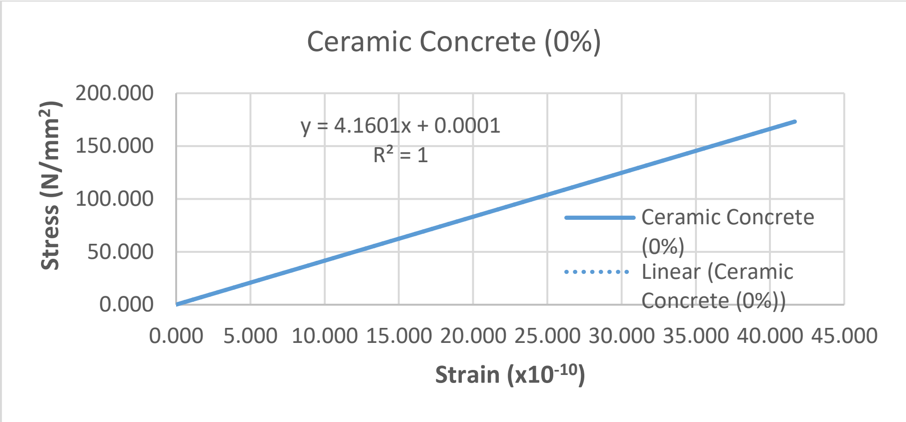


Figure 9: Graph of displacement against time for all the cube models

4.3 Stress vs Strain Deformation Graph (Cylinder Concrete Specimen)

The tabulation of the slope for the stress versus strain graph are contributed by the variable data result of the young modulus where the stress versus strain curvature in the elastic region are defined as the elastic modulus, E. The Concrete Cylinder Specimen should be designed so that any applied load would not cause the stress in the structure to be greater than yield stress of the material. Below in Figure 10 are the stress versus strain of all the proportions ranging from 0.00 % to 60.00 %.

From Figure 10 below, the value of R^2 recorded the same for all ceramic concrete proportions, with value $R^2 = 1$. The linear equation of normal concrete was y = 4.1601x + 0.0001, while ceramic concrete cylinder of 20.00 % recorded linear equation as y = 4.19x + 0.0008, ceramic concrete cylinder of 40.00 % recorded y = 4.28x + 0.0003 and ceramic concrete cylinder of 60.00 % was y = 4.21x - 0.0002. All the ceramic concrete resulted in difference value as each concrete contained different amount of ceramic concrete.



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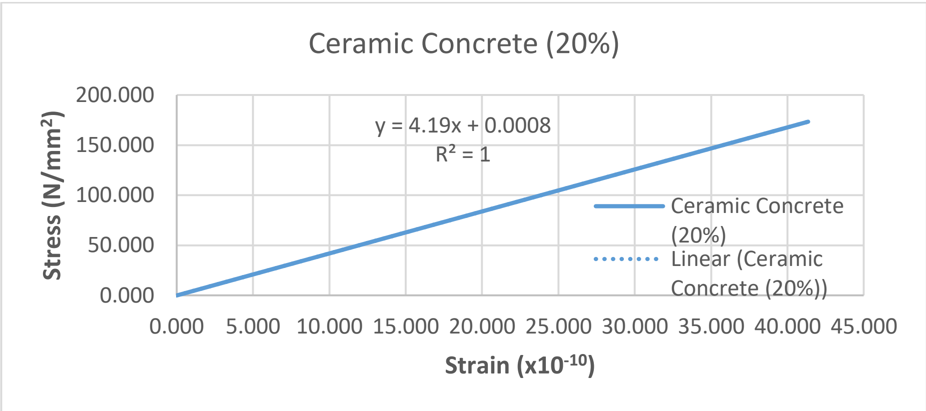

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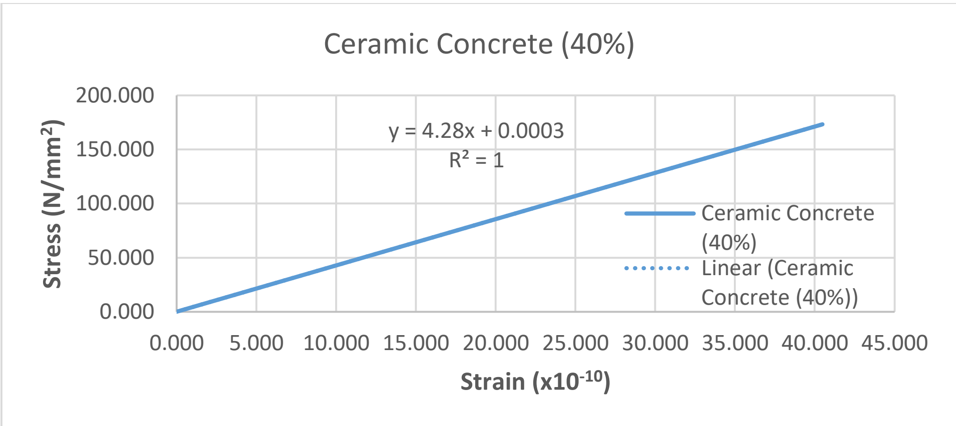

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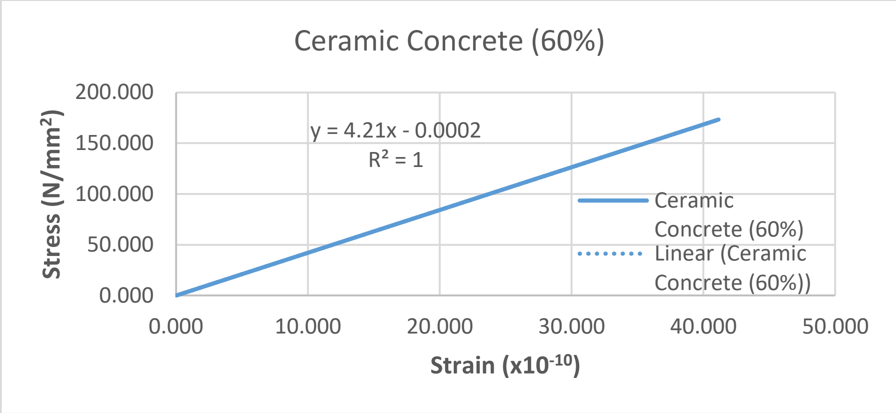


(d)

Figure 10 (a): Graph of stress against strain for normal concrete cylinder model, (b) Graph of stress against strain for ceramic concrete cylinder model (20%), (c) Graph of stress against strain for ceramic concrete cylinder model (40%) and (d) Graph of stress against strain for ceramic concrete cylinder model (60%)

Figure 11 shows that there was slightly difference between stress values for all ceramic waste concrete. By comparing all the graphs, ceramic concrete of 40.00 % recorded maximum value of gradient with 4.28. The maximum value of gradient referring to highest stress value or peak stress. The slopier the graph, the highest the stress value would be, and best choice for concrete in refrain high value of load. It can be concluded that the stress strain of cube models recorded the same pattern with previous study. Previous study stated that the highest compressive strength was on 40.00 % partial replacement of ceramic waste aggregate in concrete mixture [37].

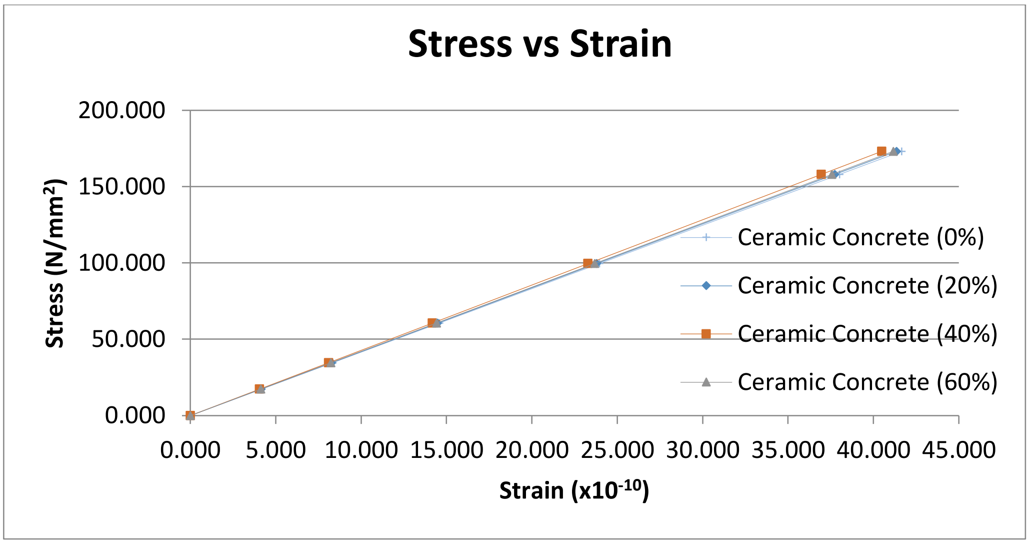
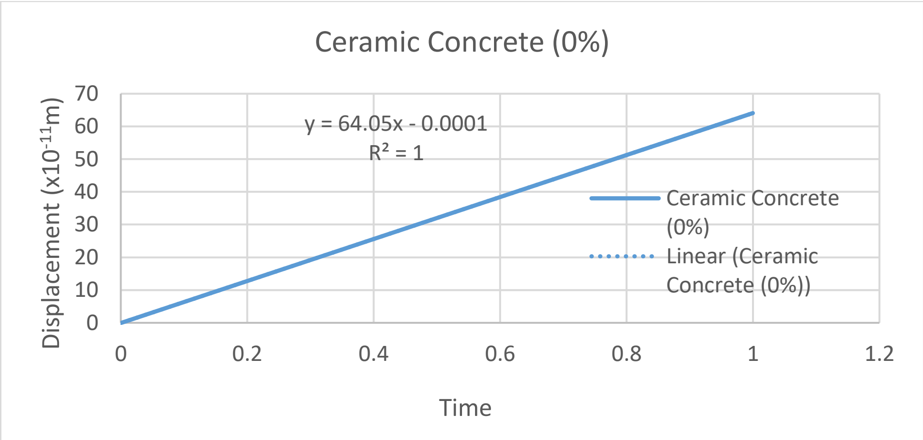


Figure 11: Graph of stress against strain for all the cylinder models

4.4 Displacement vs Time Deformation Graph (Cube Cylinder Specimen)

A displacement-time graph shows on how the displacement of a moving object changes with time. A sloping line on a displacement-time graph shows that the object is moving. Hence, this scenario is just the same to the concrete properties. If the displacement-time graph produced a sloping line, means that the concrete properties is moving when load is applied on it.

From Figure 12 below, the value of R^2 recorded the same for all ceramic concrete proportions, with value $R^2 = 1$. The linear equation of normal concrete was y = 64.05x - 0.0001, while ceramic concrete cube of 20.00 % and 40.00 % recorded as y = 63.591x - 6E-05 and y = 62.254x - 7E-05 and ceramic concrete cube of 60.00 % was y = 63.289x + 6E-05. All the ceramic concrete resulted in difference value as each concrete contained different amount of ceramic concrete.



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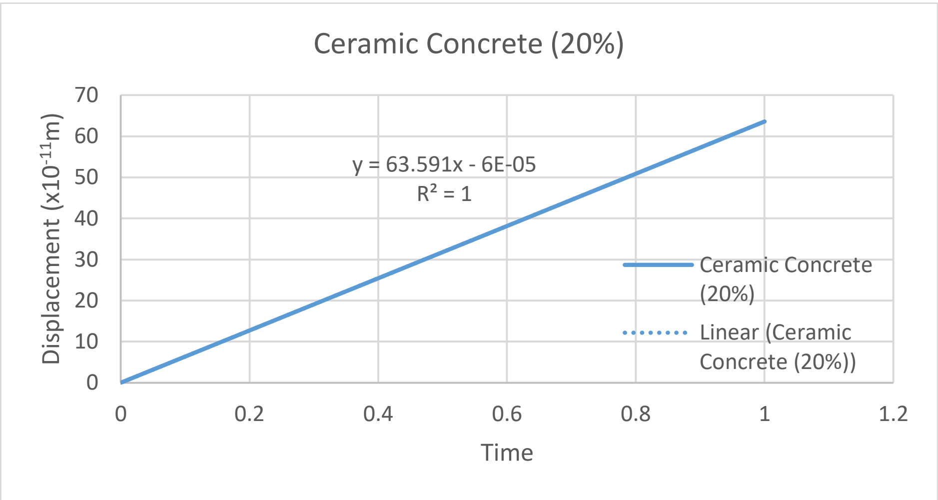
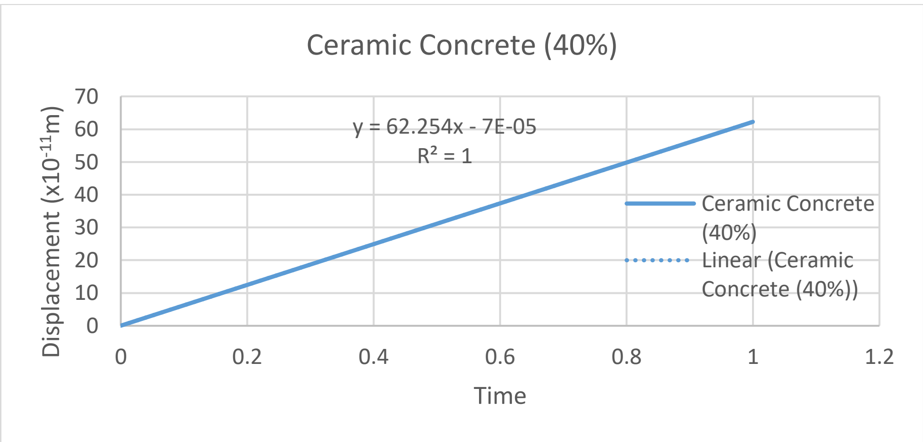
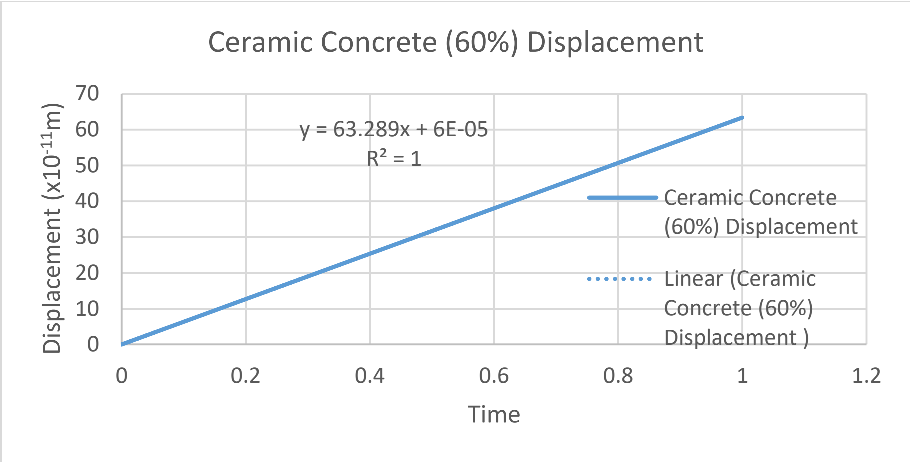


(b)



(c)



(d)

Figure 12 (a): Graph of displacement against time for normal concrete cylinder model, (b) Graph of displacement against time for ceramic concrete cylinder model (20%) (c) Graph displacement against time for ceramic concrete cylinder model (40%) and (d) Graph displacement against time for ceramic concrete cylinder model (60%)

Figure 13 shows that there was slightly difference between stress values for all ceramic waste concrete. By comparing all the graphs, ceramic concrete of 40.00 % recorded minimum value of gradient with 62.254. The minimum value of gradient referring to lowest strain value. The lowest the gradient of graph, the lowest the strain value would be, and best choice for concrete in refrain high value of load. It can be concluded that the displacement of cube models recorded the same pattern with previous study. Previous study stated that the highest compressive strength was on 40.00 % partial replacement of ceramic waste aggregate in concrete mixture [37].

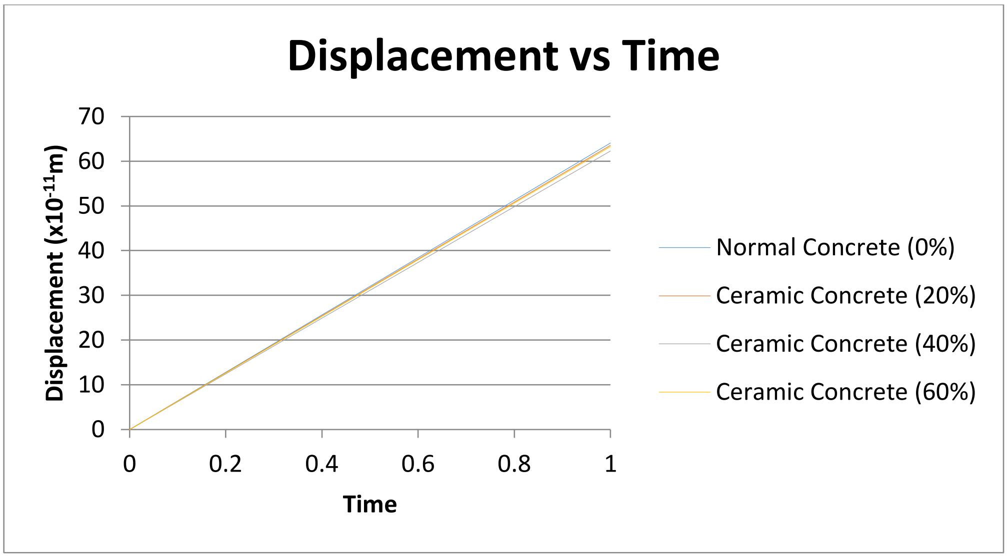


Figure 13: Graph of displacement against time for all the cylinder models

5. Conclusion

Two types of model had been successfully being developed in this study, which were cube model and cylinder model of ceramic waste concrete by using Abaqus software version 6.14. The models that were being conducted in the Abaqus software, produced the same pattern results for ceramic waste concrete cube and ceramic waste concrete cylinder, by referring to previous data study. The compressive strength of ceramic waste concrete at 40.00 % replacement recorded the highest strength compared to normal concrete and others partial percentage replacement. Concrete cube displacement of ceramic waste concrete at 40.00 % also recorded the lowest gradient among the others. Next, for cylinder models, also recorded the same trend, where ceramic waste concrete at 40.00 % recorded the lowest strain value. Same goes to cylinder concrete displacement, ceramic waste concrete also recorded the lowest displacement among others.

There are still have space for progress in any research project for improved and more reliable outcomes. There are also program drawbacks and technological issues with the simulation aspect. Recommendations for optimizing outcomes are as follows:

i. To obtain the accurate result, it is important to collect more important data information that can be insert into the Abaqus, hence, making it easy to execute various range of graph and data analysis.
ii. The value of node in meshing need to increase to obtain the precision result data.
iii. Using the latest updated of ABAQUS software to get the latest features and make the progress of analyses data running smoothly.
iv. Related research in feature may be carried out using the same methods but different in the proportion of ceramic waste, or even different in input data.

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