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Effect of Ceramic Waste Aggregate in Concrete to Reduce Environmental Pollution

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***Abstract**: The utilization of ceramic waste is one solution to reduce environmental pollution due to development waste. The aim of this study was to utilize ceramic waste as a concrete aggregate material. The test consisted of the mechanical properties test of ceramic waste aggregates and the compressive strength test of ceramic concrete. The variation of normal aggregate partial replacement with the aggregate of CWA is 0%, 25%, 50%, 75%, and 100%. The total number of specimens is 50 cylinders. From the results of material testing and ceramic concrete tests showed that ceramic waste aggregate can be used as concrete aggregates, especially for elements that accept compressive forces, shear forces, and in-plane forces. The X-ray test shows that CWA aggregate is not pozzolanic, so it can be used as a concrete aggregate to reduce environmental pollution. The percentage porosity of ceramic concrete is smaller than the porosity of normal concrete. The effect of partial replacement of normal aggregate with the CWA aggregate in concrete optimum at a value of 55% CWA aggregate.*

***Keywords**: Ceramic concrete, ceramic waste aggregate (CWA), environmental pollution.*

I. INTRODUCTION

The use of industrial building materials and ignorance of their waste can cause environmental pollution. The current development period, especially the development in the field of civil engineering, require supporting materials starting from the aspect of human resources and material resources. The use of massive natural resources and environmental hazards caused by the disposal of construction waste have reached alarming proportions so the utilization of new renewable energy and waste utilization is a must. At first glance, it seems that civil engineering materials like cement will still dominate. Like other industries, advances in the material field must also consider energy savings. As a result, it is certainly expected and emphasized that there are thoughts of using waste materials to be useful as building materials, one of which is a ceramic waste as a concrete aggregate. There are so many methods that have been taken by experts such as recycling.

Though getting similar materials is increasingly rare.

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While research on the use of renewable energy such as bamboo as concrete reinforcement has been carried out in an effort to create a green environment without pollution, including by [1], [2], [3], [4], [5], and [6].

The ceramics are materials often used in civil engineering buildings. As is known that the material for making ceramics consists of several elements such as silica (SiO_2), feldspar (Kal_3O_8), kaolin, clay, and others. The ingredient is processed from grinding, drying, to the combustion stage (sintered) at a certain temperature. Ceramic fragments have a sharp texture on the sides, ceramic waste is difficult to react with the soil, and can deliver radiation. This is very dangerous for the environment. Several previous researchers have carried out research on ceramic waste from microstructural and material aspects [7], solutions and methods of use as aggregates [8], the form of waste, the impact, and stability of radiation [9]. Turner [10] examines lead pollution due to ceramic waste on the beach and concludes that the presence of glazed ceramics that have been eroded to sizes < 2 mm result in increases in Pb concentrations relative to a regional baseline of about an order of magnitude and enrichment factors normalized to Rb of between 5 and 13. Porcelain ceramics are very heat resistant and durability against pressure, however, this ceramic cannot be recycled to return to production [11]. Seeing this negative and positive impact, a solution is needed to utilize it as a building material, including as an aggregate of concrete.

The ceramic waste can be used as a concrete material such as a partial substitute for cement, fine aggregate, or coarse aggregate. Use Ceramic waste powder as an alternative cement replacement has been done by researchers. Lasseuguette [12] concluded, ceramics containing mortar as a substitute for partial cement, CSH concentrations associated with compressive strength, higher CSH content showed an increase in mechanical performance. Other researchers who use ceramic waste as cement replacement powder include [13], and [14].

While the use of ceramic waste as concrete aggregates has been carried out by several researchers including by [15], [16], [17], [11], [18], and [19]. All researchers revealed that the compressive strength, flexural strength, and tensile strength of concrete using CWA aggregates increased rapidly when compared to conventional concrete. Wadie [20] revealed that the use of recycled ceramic tile aggregates is promising in structural concrete applications. Siddique [15] utilizes fine bone china ceramic aggregate (FBA) in concrete mixtures and concludes that fine bone china ceramic waste can be used as an aggregate to produce durable and resilient concrete.

bone china ceramic fine aggregates (BCCFA) can be used as fine aggregates (up to 40%) in structural concrete to provide considerable strength and durability characteristics. Keshavarz and Mostofinejad [11] conclude that porcelain tile waste as coarse aggregate can increase concrete compressive strength by up to 41% while red ceramic increases to 29%.

The compressive strength of the concrete runs linearly with the percentage of an aggregate amount of ceramic waste so that the analytical hierarchy process (AHP) and the technique for order preference by the similarity to ideal solution (TOPSIS) are suitable analyzes. And it was concluded that concrete by replacing 30% conventional aggregate with ceramic waste was the best proportion [16]. The concrete durability with ceramic waste aggregates is proven to be durable [17]. However, good control of material properties is very important to improve the ability of the concrete produced [18].

II. MATERIAL AND METHODS

A. Ceramic Waste Aggregate (CWA)

The aggregate of ceramic waste is obtained from industrial wastes and residential waste in the Jember area. This ceramic waste cannot be reprocessed. The thickness of ceramic waste ranges from 5 mm to 15 mm. The various types of ceramic waste are shown in Fig. 1. Then, ceramic waste is milled with stone grinding machines to a maximum size of 5 mm for fine aggregate and 10 mm for coarse aggregate. Furthermore, aggregate testing is carried out, including: chemical composition test, absorption and water content test based on ASTM C 33-03 [21], specific gravity test based on ASTM C 127 [22], Soundness test based on ASTM C 88-99a [23], abrasion test based on ASTM C 131-01 [24], granular form test based on BS 812-105.2 [25], and gradation test based on ASTM C 33-03 [21].

Fig. 1. The various types of ceramic waste

B. Mix Proportion

Normal concrete material for this study uses Portland Pozzolana Cement (PPC), sand, coarse aggregate, and water from Jember. Replacement of partial aggregates with ceramic waste aggregates (CWA) is based on the mix design results and the planned variation of CWA aggregate. The concrete mix plan uses the modified ACI 211.1-91 method [26]. The ratio of water-cement (W/C) is taken as 0.53 for slim construction, and the maximum slump value is 100 mm and a minimum of 25 mm.

C. X-ray Diffraction

Testing of ceramic waste aggregate concrete with X-ray diffraction aims to determine whether there is a reaction between the ceramic waste aggregate (CWA) with cement. The testing phase begins by pounding enough CWA aggregate samples, then sifted until the maximum grain size is 0.3 mm. Then mix with enough cement plus water until workability is reached, then cast on the mold of the test specimens (BT-CWA). As a comparison, normal concrete specimens (BT-Normal) are made. Test specimens must are attempted to be in a damp or wet room until the age of 8 weeks. Then tested by the X-ray diffraction method to determine whether there was a reaction between the ceramic waste aggregate (CWA) with cement.

D. Compressive Strength of Ceramic Concrete

The method used in this study is True Experimental Research. The CWA aggregate and normal aggregate used consisted of coarse aggregates with a maximum size of 10 mm and a fine aggregate of 5 mm. Cylindrical specimens with a diameter of 150 mm and a height of 300 mm. The variation of normal aggregate partial replacement with the aggregate of CWA is 0%, 25%, 50%, 75%, and 100%. The total number of specimens is 50 cylinders. A universal testing machine (UTM) with 2000 kN capacity was used for a compression test. Test of concrete cylinder compressive strength based on ASTM C 39 [27]. Concrete cylinder testing is carried out after 28 days. Testing of the compressive strength and modulus of elasticity as shown in Fig. 2.

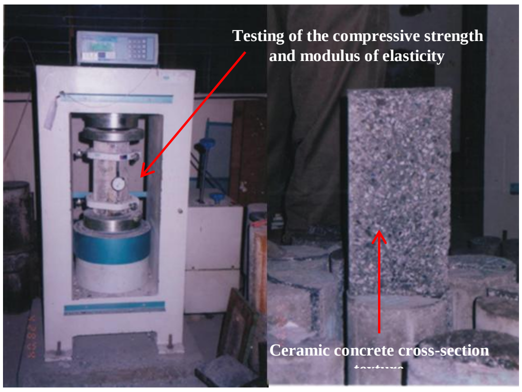

Fig. 2. Testing of the compressive strength and modulus of elasticity

III. RESULTS AND DISCUSSION

A. Chemical Composition

The chemical elements of ceramic waste aggregate (CWA) from the results of chemical laboratory tests show that the aggregate of ceramic waste contains chemical elements that are detrimental and beneficial as shown in Table 1, including (1) Silicate (SiO_2) and Feldspar ($KALSi_3O_8$), these two compounds are silicate compounds which can cause cracks in concrete and have low tensile strength but have high hardness. Aggregates that contain a lot of silicates will cause the material to become ductile or brittle, but have high compressive strength, this is evident from the results of the abrasion test of ceramic waste aggregates which has a relatively small percentage of destruction which is 17.88%. (2) As for other elements, such as elements AL_2O_3, CaO, Na_2O, and Fe_2O_3 are oxide compounds commonly found in cement, so that these elements do not have a bad impact on concrete.

Table-1: Chemical Composition Data of CWA Aggregate

Component	Specimens					Average of chemical composition (%)
	I	*II*	*III*	*IV*	*V*	
SiO_2	80.13	82.03	83.12	80.12	83.20	81.72
AL_2O_3	11.09	9.61	8.04	9.23	9.11	9.42
CaO	0.30	0.41	0.36	0.42	0.35	0.37
Na_2O	0.21	0.16	0.25	0.23	0.18	0.21
Fe_2O_3	0.49	0.41	0.58	0.47	0.51	0.49
$KALSi_3O_8$	4.89	4.29	5.33	4.82	4.71	4.80

B. Mix proportion

From Table 2, the composition of the normal concrete mixture for 1 m^3 of concrete requires 411 kg of cement, 950 kg of fine aggregate, 676 kg of coarse aggregate, and 218 kg of water, or in a ratio of 1:2.3:1.65. While for the composition of the ceramic concrete mixture for 1 m^3 of concrete requires 411 kg of cement, 670 kg of fine aggregate, 664 kg of coarse aggregate, and 218 kg of water, or in the ratio 1:1.63:1.61. From the composition of the mixture of normal concrete and the composition of ceramic concrete mixture, the weight of fine aggregate is greater than the weight of coarse aggregate, this is due to the fineness modulus of fine aggregate < 3 and a maximum coarse aggregate size of 10 mm, so the coarse aggregate composition is 44% per-m^3 concrete . While the weight of normal fresh concrete is heavier than the weight of fresh ceramic concrete, this is due to the density and weight of the normal aggregate volume greater than the CWA aggregate density and the weight of the CWA aggregate volume.

Table-2: Composition of the Concrete Mixture

Concrete Type	Cement (PPC)	Fine Aggregate	Coarse Aggregate	Water	Weight of fresh concrete
	Kg/m³				
Normal concrete	411	950	676	218	2255
Ceramic concrete	411	670	664	218	1963

C. X-ray Diffraction

Table 3 shows the results of X-ray Diffraction tests on two samples, namely normal concrete (BT-Normal) and ceramic waste aggregate concrete (BT-CWA).

From Table 3, the results of the X-ray diffractometer identification phase showed that there was a difference in the material between normal concrete (BT-Normal) and ceramic waste aggregate concrete (BT-CWA). In BT-Normal concrete, there are Portlandite [$Ca(OH)_2$] and Anorthite, Sodian, intermediate [$(Ca, Na)(Si, Al)_4O_8$] ingredients. Whereas BT-CWA concrete contains Portlandite [$Ca(OH)_2$], Quartz [SiO_2], Calcium Silicate Hydrate [$Ca_1.5SiO_3.5!xH_2O$], Dioxolan Hydrate [$C_3H_6O_2!17H_2O$], Copper Nitrate Hydrate [$Cu(NO_3)2!6H_2O$]. Two types of concrete, there is no material that can react with cement or damage concrete, such as alkali, acid, sulfate and chlorite.

Table-3: Data Results of the X-ray Diffractometers Test

Concrete type	Identified Material	Information
Normal concrete (BT-Normal)	a. Portlandite, syn b. Anorthite, Sodian, Intermediate	Testing with powder method
Ceramic concrete (BT–CWA)	a. Portlandite, syn b. Quartz c. Calcium Silicate Hydrate d. Dioxolan Hydrate e. Copper Nitrate Hydrate	Testing with powder method

Sulfate elements are usually found in ingredients such as Barite [$BaSO_4$], Anhydrite [$CaSO_4$], Alunit [$Kal_3(OH)_6(SO_4)$], Gypsum [$CaSO_4.2H_2O$]. While the active silica or amorphous silica elements such as Opal [$SiO_2.nH_2O$] or Silicate Acid [$Si(OH)_4$] which can react with alkali of cement [Na_2O and K_2O], usually found in Phyllite, Metadolerite, Granite, Dacite, and Quarsite. But in BT-CWA concrete there is silica or Quartz [SiO_2] which is quartz sand which is not reactive to alkali. In BT-CWA concrete there is no pozzolanic silica element that can react with cement $Na(OH)_2$ produced from the hydration process of C_3S and C_2S. While the material contained in BT-CWA concrete is a case of Calcium Silicate Hydrate, Dioxolan Hydrate, and Copper Nitrate Hydrate that have an effect as a filler, meaning that it does not harm concrete. Dioxolan material is a compound found in the surface layer of ceramics that functions as a glossy, and so is Copper which is an element of copper, which is a ceramic coating material (glaze), and these elements are very small.

D. Compressive Strength

Test results of compressive strength, specific gravity, and porosity are shown in Table 4. From the results of the cylindrical compressive strength test at 5 aggregate variations of CWA, it appears that the greater the CWA aggregate the greater the compressive strength, but at the variation of 100% CWA, the compressive strength occur decrease as shown in Table 4.

Figs. 3-7 And Fig. 10 shows that ceramic concrete has stiffness and the modulus of elasticity is greater than normal concrete, and the more CWA aggregate is added, the greater the stiffness and modulus of elasticity. The graph shows the ceramic concrete is more brittle and stiff than normal concrete. However, ceramic concrete has a higher compressive strength. For example, the comparison of a 0% CWA normal concrete with ceramic concrete 75% CWA, if a horizontal line is taken at 0,4*f'c* from Fig. 10, it will be seen that the normal concrete beam rigidity of 0% CWA is lower to 40% of ceramic concrete stiffness 75% CWA.

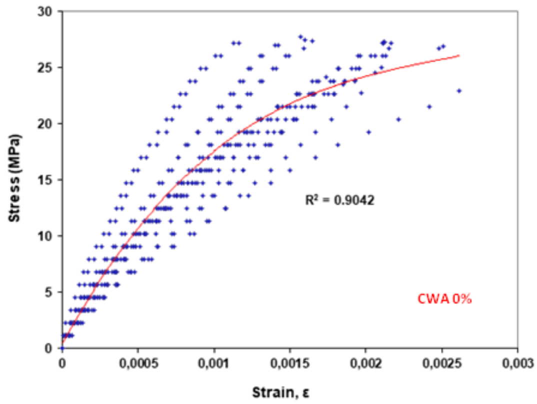

Fig. 3. The stress-strain relationship of the ceramic concrete (0% CWA)

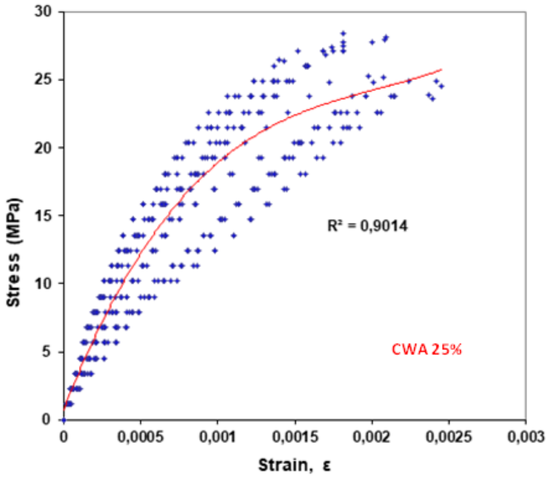

Fig. 4. The stress-strain relationship of the ceramic concrete (25% CWA)

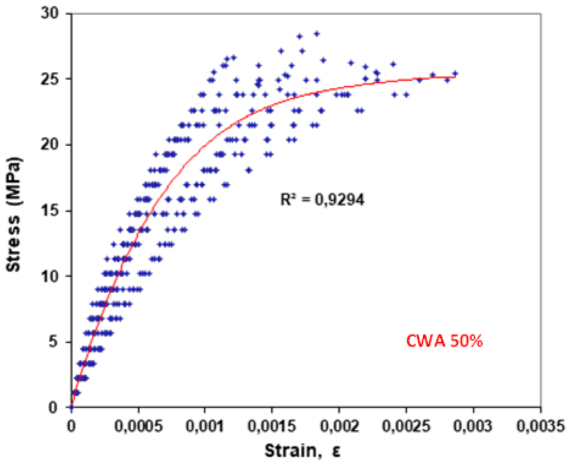

Fig. 5. The stress-strain relationship of the ceramic concrete (50% CWA)

Table-4: Data of compressive strength, specific gravity, and porosity

Concrete type	Compressive strength (MPa)	Specific gravity	Porosity (%)
Normal concrete 0% CWA	22.962	2.332	8.958
Ceramic concrete 25% CWA	23.536	2.471	8.210
Ceramic concrete 50% CWA	24.011	2.458	8.060
Ceramic concrete 75% CWA	25.017	2.363	5.824
Ceramic concrete 100% CWA	23.060	2.334	6.690

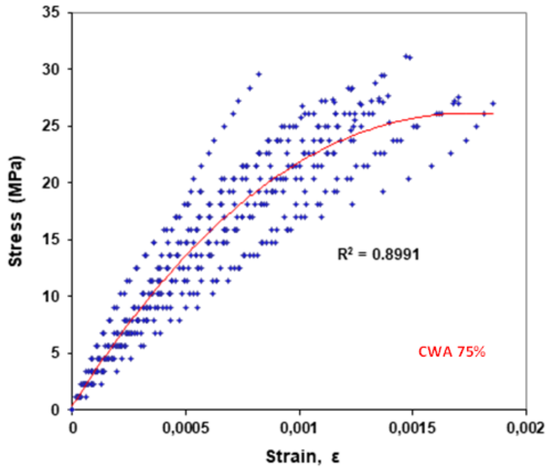

Fig. 6. The stress-strain relationship of the ceramic concrete (75% CWA)

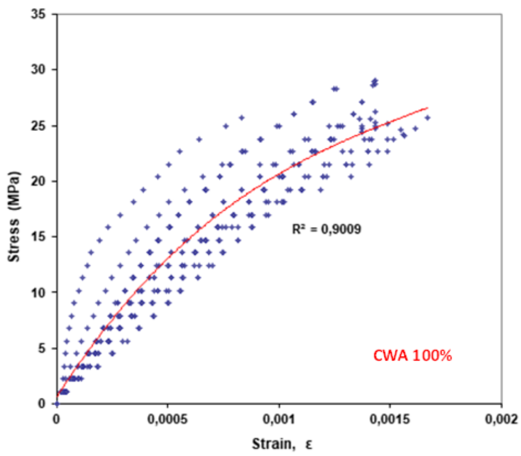

Fig. 7. The stress-strain relationship of the ceramic concrete (100% CWA)

The compressive strength of concrete is influenced by several factors including cement water factor, density, aggregate properties, the method of implementation, the age of concrete, and type of cement. All these factors must be achieved as much as possible in order to get the perfect concrete strength. The compressive strength of ceramic concrete is greater than the compressive strength of normal concrete, this is due to the porosity of normal concrete greater than the porosity of ceramic concrete which is between 5.825%-8.21% while the normal porosity of the concrete is 8.958% as shown in Table 4. The presence of air content of 5% can reduce the pressure of the concrete to 35% and the pores as much as 10% can reduce the strength of the concrete press up to 60%. Fig. 8 shows the relationship of compressive strength and porosity of the concrete with a partial variation of the aggregate replacement of CWA. The compressive strength increases with the addition of the aggregate percentage of CWA. The Compressive strength increases with decreasing porosity. Ceramic concrete has a higher compressive strength of up to 8.95% and has a smaller porosity up to 53.81% than normal concrete. This proves that the main factor affecting the compressive strength of brittle material is porosity, both the aggregate porosity used and the porosity of the hard concrete itself.

Shen and Xu [28] conclude moisture content had a significant effect on compressive strength, and this effect increased with increasing porosity. The compressive strength of normal concrete is also strongly influenced by the size of the aggregate. In this research, normal aggregate size is coarser than the CWA aggregate. Kim [29] mentioned that decreasing the maximum aggregate size, i.e. increasing the surface area of the aggregate reduces unit bond stress between cement paste and aggregate for normal strength concrete. Accordingly, the compressive strength of normal strength concrete tends to increase as the maximum aggregate size decreases.

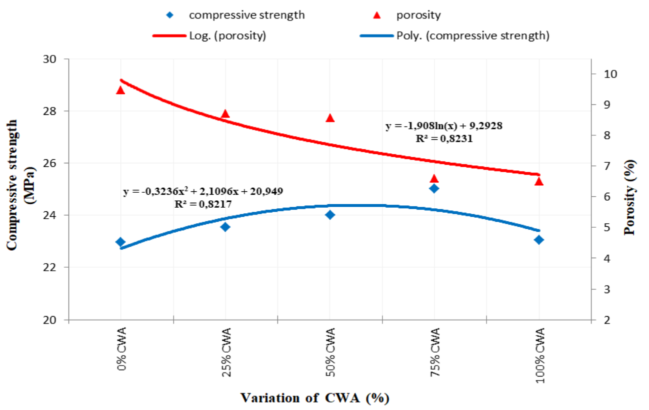

Fig. 8. The model of compressive strength and porosity relations with the CWA variation

Fig. 9 shows that the partial replacement of normal aggregate with the CWA aggregate in optimum normal concrete at a value of 55% CWA aggregate. Siddique [30] in its conclusion revealed that the replacement of fine aggregates with ceramic waste aggregate up to 40% in structural concrete to provide considerable strength and durability characteristics. Rashid [16] concluded that a replacement of 30% aggregate of ceramic waste with conventional aggregates provides the highest compressive strength. The difference of researchers in the optimal percentage of the partial replacement of normal aggregates with the CWA aggregate shows a difference in the ceramic waste studied.In addition to water-content and concrete porosity, the aggregate is an important factor to increase the compressive strength of concrete, the following aggregate properties of CWA that affect ceramic concrete compressive strength: (1) CWA aggregate violence is relatively high. This is because the CWA aggregate contains fairly large silica elements and silica has a hardness rating of 7 according to the Mohs scale. (2) The shape of the granules, the aggregate of CWA contains a lot of flat grains with sharp angles and slightly oval. Whereas normal aggregates, especially fine aggregates, consist of natural sand (rivers) which contain a lot of round oval granules, so that when these aggregates are combined there will be a balance in the compactor, because it will fill each other's gaps, especially on flat aggregates, so that ceramic concrete becomes denser. This is evidenced by the ceramic concrete porosity of 75% CWA smaller than the ceramic concrete porosity of 100% CWA and 0% CWA, and the ceramic concrete compressive strength of 75% CWA is greater than the ceramic concrete 100% CWA and 0% CWA as shown in Table 4.

From Fig. 9 shows the compressive strength relationship with variations of CWA is strong and positive with a correlation coefficient (R) of 0.906 and terminated coefficient (R^2) of 0.8217 means that a stress increase of 82% is caused by the addition of variations in CWA, the remaining 18% by other factors.

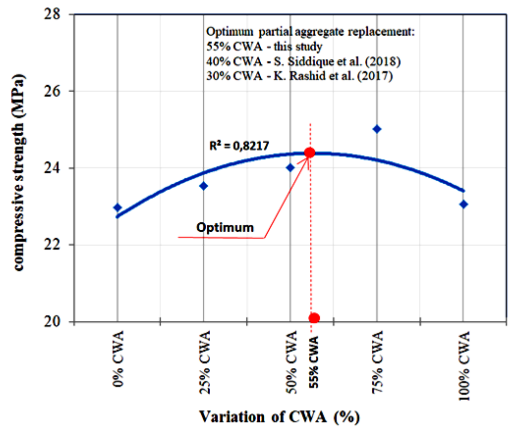

Fig. 9. The relationship graph of compressive strength with the CWA variation

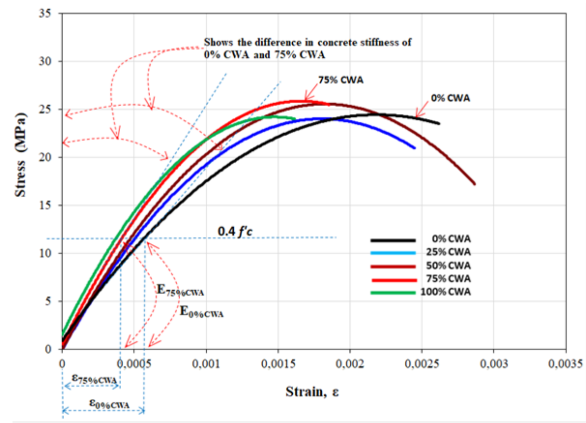

Fig. 10. The stress-strain relationship of the ceramic concrete (CWA)

Based on the results of testing of ceramic waste aggregate materials and performance tests of ceramic concrete shown compressive strength and elasticity modulus a greater of than normal concrete, while its tensile strength is smaller than normal concrete. Therefore ceramic concrete can be applied to elements that accept compressive forces and require a large elasticity modulus. Some of the elements mentioned above include columns; panels or walls that accept compressive and shear forces, both due to earthquake forces and due to gravitational forces, thin shells that can only accept normal stress or apply membrane theory.

IV. CONCLUSIONS

Based on the results of testing of ceramic waste aggregate materials and performance tests of ceramic concrete obtained several conclusions:

- X-ray test shows that aggregate CWA is not pozzolanic, so it can be used as a concrete aggregate, while still paying attention to the maximum gradation according to the thickness and slippery surface of the ceramic waste, economic and performance aspects.

- The compressive strength of concrete is strongly influenced by porosity. The smaller the porosity percentage, the higher the compressive strength and vice versa
- The effect of partial replacement of normal aggregate with the CWA aggregate optimum at a value of 55% CWA aggregate. Ceramic concrete has compressive strength and elasticity modulus a greater of than normal concrete, while its tensile strength is smaller than normal concrete. So that ceramic concrete recommended for be applied to elements that accept compressive forces and require a large elasticity modulus, such as a column; panels or walls that accept compressive and sliding forces, thin shells that can only accept normal stress or apply membrane theory.

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