Research Paper

Experimental Analysis of Recycled Concrete Microstructure Using Natural Aggregate Replacement Materials

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ABSTRACT

Solid waste from construction residues can be used as a material for forming recycled aggregate concrete materials with economic value. The use of concrete waste as a substitute for coarse aggregate is expected to be able to overcome problems in environmental pollution. The addition of a superplasticizer to the fresh concrete mix can increase the strength of the concrete produced with a small amount of water. This study aims to determine the morphological composition of the recycled concrete microstructure by SEM testing and to determine the effect of natural aggregate substitute materials on the mechanical properties of recycled concrete. Variations of waste concrete used were 0%, 50%, and 100%. The compressive strength and flexural strength tests were carried out at 28 days of concrete age. The test results show that the value of the compressive strength of concrete is 40.54 MPa at 100% concrete waste variation. Aluminum (Al_2O_3), Sulfur Trioxide (SO_3), Phosphorus (P_2O_5) and Lime (CaO) are the most dominant elements in the hydration process of concrete.

1. Introduction

Concrete is obtained by mixing several materials consisting of sand, gravel, crushed stone, or other aggregates which are mixed with a paste made of cement and water to form a rock-like mass. Sometimes one or more additives are added to produce concrete with certain characteristics, such as workability, durability, and hardening time. Various research efforts have been carried out to obtain advances in concrete technology, namely the addition of added materials aimed at reducing the use of cement to make it more economical, but not eliminating the characteristics of the concrete itself.

The use of concrete materials in various construction applications, of course, has an impact on the supply of the concrete-forming materials themselves. Nature has limitations in providing concrete-forming materials due to continuous mining. This causes a decrease in the amount of natural resources available for concrete purposes. One alternative that can be used to overcome this is by utilizing wastes around the environment as additives or substitutes for aggregates.

On the other hand, there are several environments that produce solid waste from excess concrete after construction work and the remnants of the demolition of old construction. Solid waste can affect the environmental balance so that it requires a place for disposal. This is an obstacle that needs to be considered for sustainable development. Through past researches and developments in concrete technology that have been carried out, solid waste from construction residues can be

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utilized as a material for forming recycled aggregate concrete materials that have economic value.

Recycled aggregate concrete is a concrete mixture that uses waste concrete fragments as a substitute for the aggregate making up concrete, in this case, it is used as a substitute for coarse aggregate. Based on SII No. 0052-80, most of the results of the breakdown of concrete meet the requirements of aggregate for concrete so that the materials resulting from the breakdown of concrete can be used as aggregates that make up concrete.

Along with the development of technology in the field of construction, the construction of concrete structures is also experiencing very rapid development. The construction of structures in even difficult areas such as in coastal areas and the marine environment has been widely carried out. Due to the rapid development, nature has limitations in providing materials. Not only in terms of coarse and fine aggregates that affect the environmental balance due to mining, but also fresh water as a form of concrete is something that must be investigated in order to find other alternatives in using fresh water as a form of concrete.

Data from the United Nations and the World Meteorological Agency predicts that in 2025 around 5 billion people will lack clean water (freshwater) and even drinking water. There is a possibility that when freshwater is depleted, policies or regulations will arise that require the use of clean water (freshwater) only for primary needs. Therefore, it is necessary for the world of concrete construction to think about alternative uses of seawater as concrete mixing water to minimize the use of freshwater.

Based on the things that have been described previously, the authors are interested in conducting research on the immersion of recycled concrete that is soaked in seawater.

This study aims to determine the morphological composition of the recycled concrete microstructure by SEM testing and to determine the effect of natural aggregate substitute materials on the mechanical properties of recycled concrete.

2. Literature Review

The results of testing the characteristics of aggregates in lightweight concrete shard waste showed that for testing the sieve analysis, fineness modulus and silt content all met the ASTM specifications. For testing the specific gravity, absorption, moisture content, and wear on the waste lightweight concrete fragments do not meet the ASTM specifications. The results of the flexural strength test of concrete showed an increase for each variation of the test object. At the age of 28 days, the average flexural strength of normal concrete (100% split) is 6.67 MPa, concrete with 100% LPBR is 3.33 MPa, while concrete with 50% LPBR and 50% split is 4.00 MPa (Bahar, 2012).

Dumyati (2015) suggests that:

- Sampur Beach sand meets the required fine aggregate specifications, namely entering the type III sand criteria, namely moderately fine sand with a fineness modulus of 3.09, specific gravity (Bulk) 2.607, saturated dry surface density 2.637, apparent density (Apparent) 2.688 and Absorption 1,153.
- Sampur Beach Sand with treatment, can be used as fine aggregate because it meets the normal concrete compressive strength criteria of 17.5 MPa
- The compressive strength of concrete using new desert sand (normal concrete) produces an average of 28.68 MPa
- The compressive strength of the concrete treated with washed Sampur Beach sand produces an average of 22.14 MPa
- The compressive strength of concrete with the treatment of watered Sampur Beach sand produces an average of 17.52 MPa
- The compressive strength of concrete with untreated Sampur Beach sand produces the smallest average value of 16.36 MPa.

The results of microstructural testing on SCC concrete have differences in porosity, type, and quality of compounds formed, types, and pore sizes. One reason is the difference in water used in mixing and curing. The most basic thing in SCC which uses seawater both as mixing water and curing water is the influence of salt that affects the reaction process that occurs in the chemical bonds of concrete. Microstructural testing was carried out by XRD test, SEM test, and petrography on all types of test objects. The morphology of the SEM results in the SCC microstructure which uses freshwater/freshwater as mixing water shows that there are larger pores and varies in size compared to the SCC microstructure which uses seawater/seawater as mixing water. Meanwhile, from the XRD test results, the microstructure of SCC since the age of 1 day has formed CSH, CH, and ettringite compounds (Erniati, 2016). The average compressive strength and average tensile strength of treated concrete in seawater are 18.027 MPa and 2.506 MPa, respectively (Fauzi, 2013).

The results of the compressive strength test using a hammer test immersed in salt water with a salt content of 25%, using artificial calcium carbonate as a partial replacement of 0% portlant cement at the age of 28 days = 17.89 Mpa, 90 days = 17.52, with replacement KKB 5 % at the age of 28 days = 16.27 MPa, 90 days = 15.4

MPa, and 7.5% replacement at the age of 28 days = 12.52, at the age of 90 days = 16 MPa (Ginting, 2012).

The compressive strength of concrete experienced a significant decrease in each variation (below the initial f'c 80 MPa), the modulus of elasticity decreased steadily in each variation (Hamid et al., 2014).

With the addition of 25%, 50%, 75%, 100% recycled concrete, the characteristic compressive strength was 190.75 kg/cm^2, 175.40 kg/cm^2, 172.94 kg/cm^2, 169.24 kg/cm^2. In application in the field, for medium quality concrete, recycled concrete can be used, with a note that it reduces the design compressive strength content by 30.2% for 25% of the recycled concrete mix content (Taufik, 2015).

3. Methodology

3.1 Testing Apparatus

1. Scales with a maximum capacity of 50 kg
2. A set of filters
3. Oven
4. Los Angeles Abrasion Machine
5. Compressive Strength Testing Equipment (Tokyo Testing Machine)
6. Test Object Mold
7. Bucket
8. Concrete Mixer
9. SEM and EDS Test Equipment

3.2 Material

1. Composite Portland Cement
2. Fine and coarse aggregates (sand and crushed stone) sourced from Bili-bili
3. Waste Concrete as a substitute for coarse aggregate
4. Superplasticizer
5. The water used for the mixture is clean water.

3.3 Mix Design

Table 1. Mix Composition of High-Quality Concrete Materials.

Material	Concrete Weight (kg/m^3)	Ratio to Cement	Sample Weight (kg)
Water	250,000	0,200	1,800
Cement	1250,00	1,000	9,000
Sand	271,25	0,217	1,953
Gravel	503,75	0,403	3,627
Superplasticizer	1,25	0,001	0,009

The results of the concrete mix design using the DoE (Development of Environment) method by determining the proportion of the mixture based on SNI using a superplasticizer with a composition of 0.1 percent of the cement weight, as summarized in Table 1. The required design compressive strength is f'c = 40 MPa.

3.4 Testing Sample

The making of the testing sample is carried out based on the results of the mix design, which must be carried out in three stages as follows:

1. Mixing concrete waste, sand, cement, and water.
2. Slump test measurement
3. Pouring into the mold of the test object.
4. The release of the test object from the mold after curing for 1 day (24 hours).

Table 2. Variation in Cylindrical Sample (Sample for Concrete Quality Control Test).

No	Variations of Concrete Waste as a Substitute for Coarse Aggregate
1	0% (100% natural aggregate)
3	50% (50% concrete waste + 50% natural aggregate)
5	100% (100% concrete waste)

A cylindrical test object with a diameter of 100 mm and a height of 200 mm is mounted on a universal testing machine (UTM) in a vertical position. The loading is carried out until the test object fails (cracks identified) during the test.

3.5 Curing

Curing of concrete is done to keep the concrete always moist and reduce shrinkage of the concrete. This aims to ensure the hydration reaction process of cement takes place perfectly to avoid the emergence of cracks and the quality of the concrete does not decrease. Curing is carried out by immersing the test object in freshwater for 28 days.

3.6 Concrete Testing

The beam test is carried out with two-point loads on BN and BL on the Tokyo Testing Machine (TTM), using a monotonic loading, with a constant ramp actuator speed of 0.05 mm/s until the beam collapses.

Observations of the test beams are continuously monitored visually, especially on the development of cracks that occur due to increased loads, plastic conditions, as well as failure behavior that occurs.

Loading is carried out until the compression area on the beam is destroyed and has reached the maximum load.

Flexural testing was carried out on samples of normal beams and samples of beams that had been wire mesh installed by immersion for 1 month.

Fig. 1. Testing Setup

4. Results and Discussion

4.1 Slump Test

This slump test was carried out using an Abrams cone, with a height of 30 cm, diameter below 20 cm, and diameter above 10 cm, and equipped with a grinding stick with a diameter of 16 mm and a length of 60 cm.

The results of the slump test shown in Figure 2 with an average slump of 8 cm are in accordance with the planned slump. The cement composition is obtained by dividing water quantity by water-cement factor (FAS).

Table 3. Slump Test Result.

No	Mix Variation (%)	Test Slump (cm)	Average
1	0	8	
2	50	8	8
3	100	8	

Fig. 2. Slump Test

4.2 Compressive Strength

In Table 4, the compressive strength of the 0% cylindrical specimen of concrete waste (using natural coarse aggregate) is 42.3 MPa, while the compressive strength of the specimen using the percentage of concrete waste is 50% and 100% as coarse aggregate, respectively 40.97 MPa and 40.54 MPa. This shows that the concrete cylinder as a quality control test object meets the required compressive strength requirements of 40 MPa.

4.3 Microstructure

4.3.1 SEM (Scanning Electron Microscope)

Imaging the surface of the sample by scanning with a high beam of electrons. The electrons that interact with the atoms that make up the sample generate signals that contain information about the sample's surface topography, composition, and other properties such as electrical conductivity.

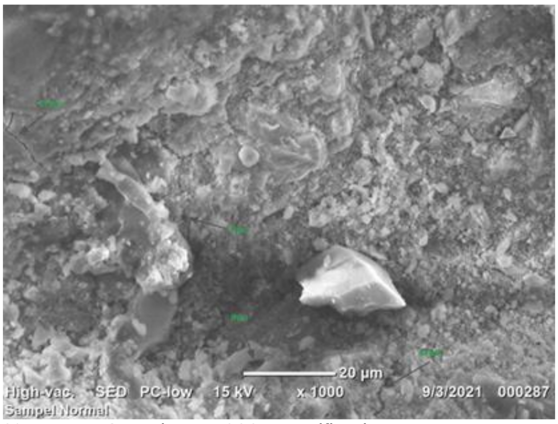
In Figure 3, you can see the results of the SEM test photos with x1000 and x3400 magnifications. In this research, it was carried out up to x5000 and x10000 magnifications, but the photos at that magnification were blurry so the resolution of the enlargement was lowered. From the SEM photo, the surface shape of normal concrete, 50% waste and 100% waste is visible: pores are formed and there are cracks that occur.

4.3.2 Qualitative and Quantitative Analysis of EDS (Energy Dispersive X-Ray Spectroscopy)

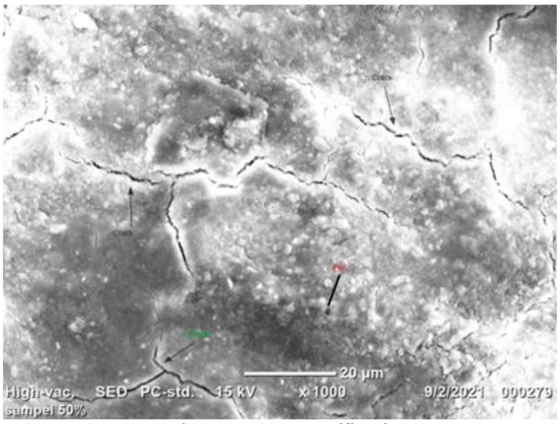
Energy Dispersive X-ray Spectroscopy (EDS or EDX or EDAX) is one of the analytical techniques to analyze the elemental or chemical characteristics of specimens.

Table 4. Result of Compressive Strength Test (Cylindrical Concrete)

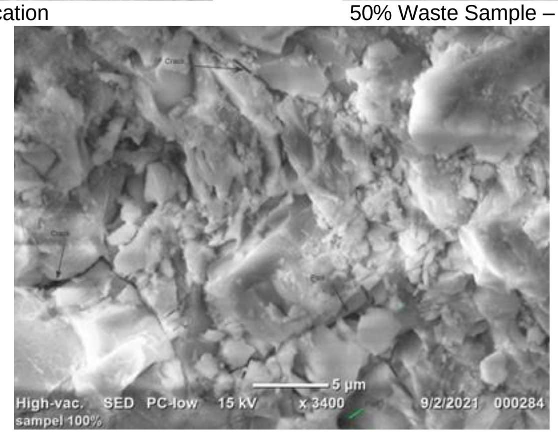
Variation and Sample No.		Height (cm)	Diameter (cm)	Area (mm2)	Weight (gram)	Max P (kN)	Average Compressive Strength (Mpa)	Average
	1	20	10	7850	3675	335,00	42,67	
0%	2	20	10	7850	3720	320,00	40,76	42,30
	3	20	10	7850	3665	340,00	43,31	
	1	20	10	7850	3725	325,00	41,40	
50%	2	20	10	7850	3565	320,00	40,76	40,97
	3	20	10	7850	3580	320,00	40,76	
	1	20	10	7850	3645	320,00	40,76	
100%	2	20	10	7850	3690	320,00	40,76	40,54
	3	20	10	7850	3720	315,00	40,12	



0% Waste Sample – x1000 magnification



50% Waste Sample – x1000 magnification



100% Waste Sample – x1000 magnification

Fig. 3. SEM Results

a. 0% Concrete Waste

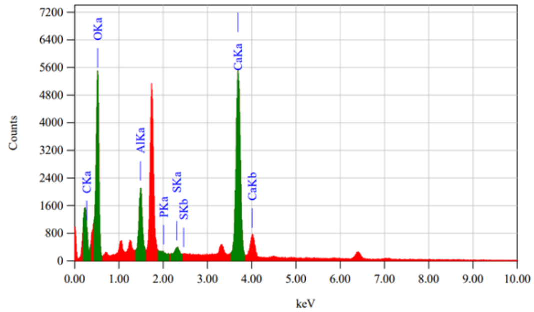


Fig. 4. Elements and Compounds EDS Results

Table 5. Description of the photo-electron kinetic energy, mass percentage, and atoms of each element

No	Element	E_k Elektron-foto (Kev)	Mass %	Atom %	Chemical Compound
1	C K	0.277	1.2	2.8	C
2	O K	0.525	23.02	40.48	-
3	Al K	1.486	9.38	9.78	Al_2O_3
4	P K	2.013	0.37	0.33	P_2O_5
5	S K	2.307	1.44	1.26	SO_3
6	Ca K	3.69	64.6	45.35	CaO
	TOTAL	**10.298**	**100**	**100**	

b. 50% Concrete Waste

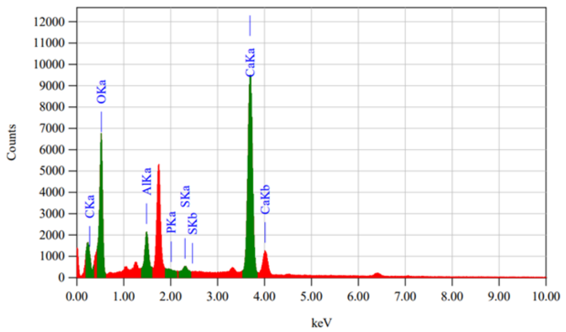


Fig. 5. Elements and Compounds EDS Results

Table 6. Description of the photo-electron kinetic energy, mass percentage, and atoms of each element

No	Element	E_k Elektron-foto (Kev)	Mass %	Atom %	Chemical Compound
1	C K	0.277	0.74	1.87	C
2	O K	0.525	18.19	34.45	-
3	Al K	1.486	5.71	6.42	Al_2O_3
4	P K	2.013	0.29	0.28	P_2O_5
5	S K	2.307	1.13	1.07	SO_3
6	Ca K	3.69	73.94	55.91	CaO
	TOTAL	**10.298**	**100**	**100**	

c. 100% Concrete Waste

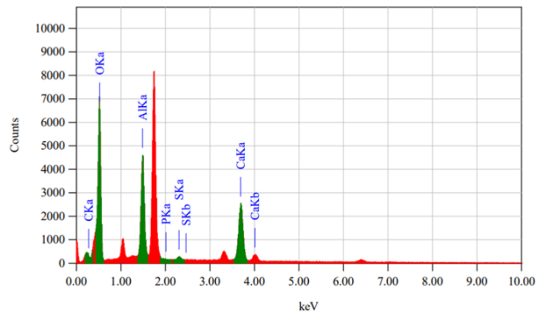


Fig. 6. Elements and Compounds EDS Results

Table 7. Description of the photo-electron kinetic energy, mass percentage, and atoms of each element

No	Element	E_k Elektron-foto (Kev)	Mass %	Atom %	Chemical Compound
1	C K	0.277	ND	ND	-
2	O K	0.525	36.00	53.76	-
3	Al K	1.486	27.16	24.05	Al_2O_3
4	P K	2.013	0.26	0.20	P_2O_5
5	S K	2.307	1.20	0.89	SO_3
6	Ca K	3.69	35.39	21.10	CaO
	TOTAL	**10.298**	**100**	**100**	

Table 8. Description of Chemical Elements

K	Subatomic shell number (quantum number n = 1)
ND	No Detection
C	Carbon
O	Oxygen
Al	Aluminium
P	Phosphorus
S	Sulphur
Ca	Calcium

From the results of concrete tests carried out in the laboratory, the chemical composition of concrete without concrete waste, concrete with 50% waste, and concrete with 100% waste, it is seen that Aluminum (Al_2O_3), Sulfur Trioxide (SO_3), Phosphorus (P_2O_5) and Lime (CaO) is the most dominant element. Thus, it can be concluded that there is a bond between the particles which is characterized by a hardening process since the mixing of water with cement and the supporting aggregates forms a new compound known as the hydration process and a change in components due to the influence of water and cement is known as hydrolysis.

5. Conclusions

Based on the results that have been obtained and the analysis that has been carried out, the authors recommend several conclusions, as follows:

1. Aluminum (Al_2O_3), Sulfur Trioxide (SO_3), Phosphorus (P_2O_5) and Lime (CaO) are the most dominant elements, thus it can be concluded that there is a bond between the particles which is characterized by a hardening process since the mixing of water with cement and the supporting aggregates form a new compound known as the hydration process and a change in the components due to the influence of water and cement is known as hydrolysis.
2. The compressive strength of the cylindrical specimen with 0% waste concrete (using natural coarse aggregate) is 42.3 MPa, while the compressive strength of the specimen using the percentage of concrete waste of 50% and 100% as coarse aggregate, respectively, at 40.97 MPa and 40.54 MPa. This shows that the concrete cylinder as a quality control test object meets the requirements for the required high strength concrete compressive strength of 40 MPa.

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