Shape and Size Effects on the Compressive Strength of Concrete Using Recycled Concrete Aggregate

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ABSTRACT: *The residual waste of ready-mixed concrete is solid waste. One way to utilise this waste is to reuse it as aggregate in recycled concrete aggregate (RCA). This is the main mechanical characteristic of concrete that can be known through laboratory compressive strength testing of cylindrical specimens with a standard size of 15cm in diameter and 30 cm in height. There is a conversion value of compressive strength test results due to differences in the shape and size of the specimen. An experimental study was conducted to obtain the conversion value of a 15x30 cm cylindrical specimen against a 10x20 cm cylinder, as well as 15x15x15 cm and 10x10x10 cm cube specimens. The test results showed the average compressive strength of the 15x30 cylinder was 30.44 MPa and the 10x20 cm cylinder was 31.47 MPa with a conversion value of 0.968 for the 15x30 cm cylinder. While the cube test specimens of 15x15x15 cm and 10x10x10 cm were 31.04 MPa and 32.58 MPa, with conversion values of 0.980 and 0.934.*

KEYWORDS: *specimen dimensions, cylindrical specimen, cube specimen, recycled concreteaggregate*

I. Introduction

The increase in human resources is accompanied by an increase in science and technology. One of the technological improvements is concrete materials, which is realised by the discovery of high quality concrete materials. Increasing the quality of concrete will increase its use, which results in increased exploitation of natural resources (crushed stone and sand). On the other hand, technological improvements have also led to an increase in the use of ready-mix concrete. Generally, ready-mix concrete is used for buildings with a large volume of concrete, and generally the order will exceed the demand, so it often happens that the remaining concrete is dumped in any place, which causes pollution. On the other hand, many buildings are forced to be demolished due to insufficient building capacity, changes in land use, and buildings that are severely damaged by earthquakes or fires. These will also lead to solid waste in the form of demolished concrete materials.

In general, concrete solid waste is used as a backfill material, which results in a decrease in soil fertility. One solution to overcome this is to reuse the waste as aggregate again, and is often called recycled aggregate, so concrete using recycled aggregate is called recycled aggregate concrete.

A major factor in the execution of work is quality control. One of the most important aspects is in determining the strength of concrete. Strength becomes an important review because in every design and planning requires strength data from the material. Therefore, laboratory testing is needed in order to determine how much strength the test specimen can bear. Loading can be adjusted to various conditions, load types, and load rates. In addition, the scale of the test object in the laboratory also affects the test results. Testing in the laboratory must be in accordance with standards that reflect the actual strength of concrete, such as tensile strength testing, elastic modulus testing and compressive strength testing. The compressive strength is the main mechanical characteristic of concrete that can be known through laboratory compressive test research on test specimens. The results of compressive strength values based on tests with cubes and cylinders can be calculated and produce different values. What if the test is carried out with various test specimen dimensions? Many studies have shown that the larger the cross-sectional size of the specimen, the smaller the compressive strength (fc) of the concrete [1]. Therefore, it is necessary to investigate the effect of the dimensions of the specimen, and the relationship between the shape of the specimen.

The compressive strength of concrete is usually obtained from testing cube or cylinder-shaped concrete specimens of different sizes as suggested by the applicable standard. SNI 2847-2019 has regulated that concrete compressive strength testing must use concrete specimens in the form of cylinders with a diameter of 15 cm and a height of 30 cm, with results using SI units, namely Mega Pascal (MPa). Meanwhile, the demands in the field until now still use the characteristic strength unit, namely kg/cm2, where the unit is used for testing the compressive strength of cube-shaped test specimens. Therefore, there is a conversion value due to changes in shape and size. The commonly used conversion only applies to concrete using normal aggregates, i.e. crushed stone natural aggregates. Does the shape and size conversion also apply to recycled aggregate concrete?

II. Literature Review

The volume of solid waste globally continues to increase alarmingly. Currently, the world generates about 1.3 billion tonnes of solid waste per year, and is expected to reach 2.2 billion tonnes by 2025 [2]. The construction industry is one of the sectors in the world that generates large amounts of waste, both in volume and weight [3]. Construction and demolition waste (CDW) consists of a heterogeneous mixture of materials in which the majority, i.e. 40% to 85%, are inert materials [4].

Among the intermaterials, the largest fraction is concrete waste. Although the construction industry generates a large amount of waste, there is an increasing interest in utilising non-CDW waste as construction materials. For example, there are studies on the utilisation of carpet fibre waste materials and palm oil fuel ash [5], textile sewage sludge [6], used tyre rubber [7, 8], electric arc furnace slag [9], and fly ash [10, 11]. There are also studies on the benefits of agricultural waste, e.g. bagasse fibre and cotton stalks, in the manufacture of building materials [12, 13].

The waste generated by the construction industry in developing countries is high due to inefficient construction and waste management practices. CDW in these countries will increase exponentially further as construction activities will expand because of rapid economic growth, industrialisation, and urbanisation. In addition, as part of the urbanisation process, old infrastructure that does not meet current functional or structural requirements is demolished resulting in more CDW. This will further exacerbate the existing capacity constraints in managing waste. Currently, most CDW in some developing countries is mainly disposed of in landfills, causing social, environmental and economic problems. The adverse impacts of CDW on health and the environment and with the ever-increasing demand for buildable land, disposing of CDW in landfills has never been thought of before.

The demand for natural aggregates for concrete production is projected to grow by an average of 7.7% per year, reaching 66.2 billion metric tonnes by 2022 [14]. Much of this natural aggregate demand is from developing countries as a result of rapid growth in industrialisation and urbanisation. The utilisation of recycled aggregates from concrete waste for new construction can significantly help conserve natural resources and reduce waste disposal and transportation, in turn gaining economic and environmental benefits. Recycled concrete aggregate (RCA) is used in developed countries as a substitute for natural coarse aggregate for the basic stability of road construction, aiming at saving natural materials for future generations. Although the use of CDW recycled aggregates greatly improves the ecological footprint of concrete, the utilisation of RCA in construction activities in some developing countries is still limited. The main reason is the lack of trust or knowledge on how concrete waste can be recycled into new concrete or other construction materials.

Concrete is produced from a set of mechanical and chemical interactions of a number of forming materials. In the process of making concrete, it is strongly influenced by the composition of each constituent, implementation, compaction, and maintenance during drying, so that concrete is produced according to plan. Compressive strength is one of the most important properties of concrete and is the basic mechanical parameter required in the design of concrete structures. Compressive strength is the ability of concrete to accept compressive force per unit cross-sectional area. By far the most common test performed is the concrete compressive strength test. Strength is an important review because every design and planning requires strength data from the material. Therefore, laboratory testing is needed in order to determine how much strength the specimen can bear. The compressive strength of concrete is obtained from compressive testing of concrete specimens in the form of cylinders or cubes of different sizes as suggested by applicable standards. Concrete cylinder specimens (150 mm diameter and 300 mm height) are the standard specimens for testing compressive strength in the United States, while in the United Kingdom and Europe the standard specimen for testing compressive strength is a concrete cube specimen with a size of 150x150x150 mm [15] (Kim and Seong-Tae, 2002).Based on SNI 2847-2019, Regulation of Structural Concrete Requirements for Building (*Peraturan Persyaratan Beton Struktural untuk Bangunan Gedung*)[16] has regulated that concrete compressive strength testing must use 150x300mm cylindrical concrete specimens, while according to Pt T-37-2000-C, Procedure for Concrete Assessment and Acceptance of Normal Concrete during Building Implementation(*Tata Cara Penilaian Beton dan Penerimaan Beton Normal Selama Pelaksanaan Bangunan*) [17] explains that standard test specimens must meet the provisions of 150x300mm cylinders, or if there are no facilities available, the test specimens are allowed to be cubes with dimensions of 150x150x150 mm. There is a conversion value from cube test specimen to cylindrical test specimen.

Generally, the compressive strength of concrete decreases as the cross-sectional size of the specimen increases. Meanwhile, the rate of decrease remains almost constant beyond a certain size limit. The compressive strength of cubes is usually higher than that measured from cylinders, but the effect of specimen shape on the size effect is somewhat unclear [18]. Therefore, the ASTM standard sets a correction factor for concrete strength between 14 - 42 MPa, to cover the strength drop; when the aspect ratio (ratio of height to diameter) of the specimen is less than 2.0. Meanwhile, the CEB-FIP standard specifically mentions the ratio of the strength of a 150x300 mm cylinder to the strength of a 150x150x150 mm cube; although both standard requirements do not specifically explain the application and/or modification of the compressive strength correction factor in lightweight concrete [19].

The proposed laboratory work is intended to study the effect of specimen size and shape on the axial compressive strength of concrete. Specimens of various sizes and shapes were cast to investigate the compressive strength behaviour at 28 days. Hypothetically, the compressive strength will decrease as the size of the concrete specimen increases, and a cube-shaped concrete specimen will yield a compressive strength comparable to a cylinder, and a 100x100x100mm cube specimen is comparable to a 100x200 mm cylinder.

III. Research Methodology

3.1. Research Limitation

The method used in this research is the experimental method, which was conducted at the Civil Engineering Laboratory, Pakuan University. In this study, the object of study was recycled aggregate concrete with variations in the shape and size of the specimens, namely cylindrical and cube shapes. The cylinder sizes are 150x300 mm and 100x200 mm, while the cube sizes are 150x150x150 mm and 100x100x100 mm.

3.2. Material Preperation

The materials used to make concrete were Portland cement, fine aggregate (sand), coarse aggregate (gravel) and water as well as recycled aggregate from ready-mix concrete waste as a substitute for coarse aggregate. Then, as a comparison concrete, normal concrete of 30 MPa quality was also made without the addition of recycled concrete aggregate. The recycled concrete aggregate was obtained from PT Wika Beton Tbk, Cileungsi, Bogor. The recycled concrete aggregate was obtained from the remaining test specimens of projects and research, the concrete waste was crushed to form coarse aggregate with a 19 mm sieve pass.

The cement used in this study is Portland cement type I, produced by Indocement Tunggal Prakarsa Tbk. Laboratory examination of this cement was not carried out because it has met the Indonesian National Standard (SNI l5-2049-2004).

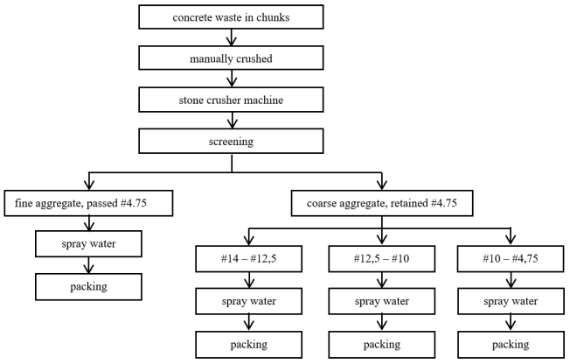
The examination was only carried out visually on the bag that was torn and there were no hard lumps in the cement.

Natural coarse aggregate (crushed stone) and natural fine aggregate (sand) were obtained from Padalarang. The examination of crushed stone coarse aggregate and sand fine aggregate as concrete forming material needs to be done to obtain good quality material (SNI 2847-2013). This examination is carried out on the properties of aggregates which include specific gravity, absorbtion, bulk density, sieve analysis, and fineness modulus.

The water used for concrete mixes and treatments comes from clean water obtained from the Civil Engineering Laboratory, Unpak. The water in this laboratory meets the standards of clean water suitable for use in concrete mixtures.

3.3. How to make recycled concrete aggregate

Steps for making recycled aggregate:



3.4. Preparation of Test Objects

The concrete mix design was planned using the SNI 7656:2012 method with a planned concrete quality of 30 MPa. Planning is based on the method of weight comparison of concrete forming materials.

The work of making normal concrete begins with the preparation of concrete forming materials, namely fine aggregate, sand coarse aggregate gravel, cement and water. The concrete is then put into a concrete mixer. In addition, fresh concrete is tested by measuring the slump test. The next job is to put the concrete into the mould for 24 hours.

The work of making concrete with recycled concrete substitution is as follows: A concrete plant, also known as a batch plant or batching plant or a concrete batching plant, is equipment that combines various ingredients to form concrete. The composition of each mix made is adjusted to the percentage of test objects. then recycled concrete is added with variations of 25%, 50%, 75% and 100% of the weight of the coarse aggregate. After the concrete mixture is stirred evenly, the next step is testing fresh concrete, namely measuring the slump height. The next job is to put the concrete into the mould waiting for 24 hours.

After the work of making concrete, then curing is carried out by soaking.

Testing the compressive strength of the cylinder is carried out after the concrete reaches the planned age, namely at the age of 28 days. Concrete is given a load in the vertical direction or parallel to the cylinder slowly until the specimen is destroyed. The total number of test specimens were 15 cylinders 15x30 cm, 15 cylinders 10x15 cm, 15 cubes 15x15x15 cm, and 15 cubes 10x10x10 cm, with variations in the percentage of recycled concrete aggregate, namely 0%, 25%, 50%, 75% and 100% by weight of coarse aggregate.

IV. Results and Discussions

4.1. Mix Design Calculation

The following are the results of the calculation of the mix-design plan calculated from the results of testing the material properties. Mix design uses the SNI 7656: 2012 reference, with a compressive strength of 30 MPa.

Table 1. Mix design calculation

Material	Amount of material for 4x3 specimens				
	Recycled concrete aggregate (RCA) percentage				
	RCA-0	RCA-25	RCA-50	RCA-75	RCA-100
Portland cement[kg]	28,95	28,95	28,95	28,95	28,95
Water [kg]	10,18	10,18	10,18	10,18	10,18
Natural coarse aggregate[kg]	70,65	52,99	35,33	17,66	0,00
RCA coarse aggregate [kg]	0,00	17,66	35,32	52,99	70,65
Fine aggregate [kg]	39,42	39,42	39,42	39,42	39,42

4.2. Slump Value

The slump value at RCA-0 and RCA-25 was 7.7 cm, while that at RCA-75 was 7.6 cm and RCA-100 was 7.5 cm. This value shows a difference, which is expected as the higher percentage of recycled concrete aggregate usage leads to higher water absorption in the concrete.

4.3. Compressive Strength Testing Results

The compressive strength of the concrete was tested at the planned age of 28 days with different percentages of recycled concrete aggregate (RCA) and different shapes and dimensions of the specimens. A planned compressive strength of 30 MPa was achieved in concrete using normal aggregate, i.e. 100% natural aggregate with a cylindrical specimen shape of 15x30 cm.

Table 2. Average compressive strength of 3 Specimens for each shape, specimen dimension, and percentage of RCA

Codes and Percentages Recycled Concrete	w/c ratio	Compressive Strength of Concrete [MPa]			
		Cylinders 15x30 cm	Cylinders 10x20 cm	Cubes 15x15x15 cm	Cubes 10x10x10 cm
RCA0 – 0%	0,48	30,02	31.06	30,64	32,14
RCA25 – 25%	0,51	28,22	29,16	28,78	30,18
RCA50 – 50%	0,54	26,80	27,70	27,34	28,68
RCA75 – 75%	0,54	23,42	24,22	23,90	25,08
RCA100 – 100%	0,54	20,38	21,10	20,78	21,82

The compressive strength of the concrete was tested at the planned age of 28 days with different percentages of recycled concrete aggregate (RCA) and different shapes and dimensions of the specimens. A planned compressive strength of 30 MPa was achieved in concrete using normal aggregate, i.e. 100% natural aggregate with a cylindrical specimen shape of 15x30 cm.

There was a decrease with each increase in RCA percentage. Concrete with 25% RCA decreased 6% from the compressive strength of normal concrete (0% RCA), with 50% RCA decreased 11%, with 75% RCA decreased 22%, and 100% RCA decreased 32%.

The reason for the decrease in the quality of concrete using recycled aggregates is due to some differences in the physical properties of recycled aggregates and natural aggregates. So that the difference in the material properties of the resulting concrete can reduce the compressive strength of the concrete. Some of the things that also affect the quality of concrete using recycled aggregates are the need for higher mix water due to the greater water absorption properties of recycled aggregates, which causes the value of the water cement factor (FAS) to change (inconsistently), which is expected to cause the compressive strength of concrete to decrease. Furthermore, the recycled aggregates produced from recycled concrete also contained 25 to 45% mortar, the mortar adhering to the recycled aggregates is expected to contribute low compressive strength values, thus causing the compressive strength of the concrete to decrease.The random selection of recycled concrete materials in the re-aggregate manufacturing process is also suspected to be the cause of the reduced compressive strength of concrete.

4.4. Crack Pattern

The results of testing the compressive strength of cylindrical specimens show that the dominant crack pattern is shear and parallel to the upright axis (columnar). In this case, shear collapse indicates that the surface of the specimen is less flat and the density is also less, so that the specimen has cracks not purely due to compression, but also due to shear. Failure due to shear occurs because when testing, the concrete cylinder is not completely retained on the top and bottom sides, but there are sides that can shift. This can reduce the actual compressive strength value of the concrete. The uneven surface of the concrete cylinder test specimen occurs due to the shrinkage that occurs in concrete during the bonding process, so that the surface decreases from its original state. While columnar collapse (parallel to the upright axis) is caused because concrete tends to have low compressive strength and destruction occurs first in the mortar, which occurs in the use of 75% RCA and 100% RCA.

4.5. Shape and Dimension Conversion Values

The conversion value is calculated as the average of the compressive strength values of each shape and dimension of the specimen.

Table 3. Shape and dimension conversion values

Shape of specimen	Size [cm]	Compressive Strength [MPa]	Faktor Konversi	ASTM Standard
cylinders	15x30	26,80	1,00	1,00
	10x20	27,70	0,968	0,97
cubes	15x15x15	27,34	0,980	0,80
	10x10x10	28,68	0,934	0,80

V. Conclusion

The research results and data processing that have been carried out, can be drawn several conclusions as the final result of this research:

– The compressive strength of the reference cylinder, which is a cylinder of dimension 15x30 cm is 30.02 MPa, in accordance with the compressive strength of the plan. This compressive strength will be used as a reference for calculating the conversion value.
– The average compressive strength of 15x30 cm cylindrical specimens with 25%, 50%, 75% and

100% recycled aggregate (RCA) were 28.22 MPa, 26.80 MPa, 23.42 MPa and 20.38 MPa, respectively.

- The average compressive strength of 10x20 cm cylindrical specimens with 0%, 25%, 50%, 75% and 100% RCA were 31.06 MPa, 29.16 MPa, 27.70 MPa, 24.22 MPa and 21.10 MPa.
- The average compressive strength of 15x15x15 cm cube specimens with 0%, 25%, 50%, 75% and 100% RCA are 30.64 MPa, 28.78 MPa, 27.34 MPa, 23.90 MPa and 20.78 MPa.
- The average compressive strength of 10x10x10 cm cube specimens with 0%, 25%, 50%, 75% and 100% RCA were 32.14 MPa, 30.18 MPa, 28.68 MPa, 25.08 MPa and 21.82 MPa.
- Concrete using recycled concrete aggregate (RCA) had a decrease in compressive strength when compared to normal concrete of 30 MPa.
- There was a decrease in the slump value of the concrete mix using RCA. This occurs due to the higher percentage of RCA usage, the higher the water absorption in the concrete mix.
- There was a change in the water cement factor (FAS) value caused by greater water absorption in concrete using RCA when compared to normal concrete. This is thought to also cause a decrease in compressive strength in concrete with the use of RCA.
- The cause of the decrease in concrete quality is due to several reasons, namely the difference in the quality of the physical properties of the aggregates, the random selection of recycled concrete aggregates (RCA), and the presence of mortar adhering to the recycled concrete aggregates which contributes to the low compressive strength values.
- The crack pattern in concrete with recycled aggregate substitution (RCA-25%) and (RCA-50%) was shear, indicating a strong bond between mortar and aggregate, compared to concrete using recycled aggregate RCA-75% and RCA-100% which had a columnar crack pattern.

References

[1] Ozyildirim, C., Carino, N. J., Concrete strength testing,in J. F. Lamond, J. H. Pielert (editor), Significance of test and properties of concrete &concrete-making material’s, West Conshohocken, 2006

[2] Hoornweg and P. Bhada-Tata, What a waste: A global review of solid waste management, World Bank,Washington, DC, USA, 2012.

[3] Rodr´ıguez, C. Parra, G. Casado et al., The incorporation of construction and demolition wastes as recycled mixed aggregates in non-structural concrete precast pieces, *Journal of Cleaner Production*, vol. 127, 2016

[4] M´alia, J. de Brito, M. D. Pinheiro, and M. Bravo, Construction and demolition waste indicators, *Waste Management and Research*, vol. 31, no. 3, 2013.

[5] S. M. A. Awal and H. M. Hosseini, Green concrete production incorporating waste carpet fiber and palm oil fuel ash, *Journal of Cleaner Production*, vol. 137, 2016.

[6] J. Zhan and C. S. Poon, Study on feasibility of reutilizing textile effluent sludge for producing concrete blocks, *Journalof Cleaner Production*, vol. 101, 2015.

[7] Hesami, I. S. Hikouei, and S. A. A. Emadi, Mechanical behavior of self-compacting concrete pavements incorporating recycled tire rubber crumb and reinforced with polypropylene fiber, *Journal of Cleaner Production*, vol. 133, 2016.

[8] S. Omas and R. C. Gupta, Properties of high strength concrete containing scrap tire rubber, *Journal of Cleaner Production*, vol. 113, 2016.

[9] Faleschini, M. A. Fern´andez-Ru´ız, M. A. Zanini, K. Brunelli, C. Pellegrino, and E. Hern´andez-Montes, High performance concrete with electric arc furnace slag as aggregate: mechanical and durability properties, *Construction and Building Materials*, vol. 101, 2015.

[10] Faleschini, M. A. Zanini, K. Brunelli, and C. Pellegrino, Valorization of co-combustion fly ash in concrete production, *Materials and Design*, vol. 85, 2015.

[11] A. Alaka and L. O. Oyedele, High volume fly ash concrete: the practical impact of using superabundant dose of high range water reducer, *Journal of Building Engineering*, vol. 8, 2016.

[12] Z. Taffese, Low-cost eco-friendly building material : a case study in

Ethiopia,*International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, vol. 6, 2012.

[13] Zhou, F. Zheng, H. Li, and C. Lu, An environmentfriendly thermal insulation material from cotton stalk fibers, *Energy and Buildings*, vol. 42, no. 7, 2010.

[14] M. Kuhar, *World Aggregates Market*, SEMCO Publishing, Denver, CO, USA, 2014, http://www.rockproducts.com/features/13045-world-aggregates-market.html#.WjFBzdx3cs

[15] SNI 2847-2019, Peraturan Persyaratan Beton Struktural untuk Bangunan Gedung, BSN, 2019

[16] Pt T-37-2000-C, Tata Cara Penilaian Beton dan Penerimaan Beton Normal Selama Pelaksanaan Bangunan

[17] J.I Sim, K.H. Yang, H.Y. Kim, B.J. Choi, Size And Shape Effects On Compressive Strength Of Lightweight Concrete, Construction And Building Materials, 2013

[18] J.R. Del Viso, J.R. Carmona, G. Ruiz, Shape and Size Effects on The Compressive Strength Of High-Strength Concrete, Cement And Concrete Research, 2008.