

The demand for self-compacting concrete is very high because this concrete has high flowability and has resistance to segregation. Natural aggregates are of high value, while concrete demolition materials are abundant and of low value. So that the recycled coarse aggregate can be used as concrete material, this study analyzes the characteristics of Self Compacting Concrete (SCC) using recycled coarse aggregate from construction waste. Tests for aggregate wear, aggregate hardness, compressive strength of concrete and tensile strength of concrete were carried out. The wear test refers to the standard AASHTO T-96-74, ASTM C-131-55 and SNI 2417-2008. This test uses recycled coarse aggregate that has been washed so that the sludge content is clean; after that, it was baked with the used aggregate, the aggregate that passed the 12.5 mm sieve and was retained in the 9.5 mm sieve. The test object is pressurized 40 tons at a speed of 4 tons/minute. Concrete Compressive Strength Test refers to SNI 03-1974-2011, using a scale with an accuracy of 0.3 % of the weight of the concrete, a concrete press machine and a capping machine. While the split tensile strength test of concrete refers to SNI 03-2491-2014, carried out on days 7, 21 and 28 with a cylindrical test object. Variations of recycled aggregates start from 0 %, 25 %, 50 %, 75 %, and 100 %. The design's compressive strength is 25 MPa. The results showed that the recycled aggregates had good gradation, high absorption and low specific gravity compared to natural aggregates. The recycled coarse aggregate reduces the compressive strength of the concrete and causes a decrease in a slump, thereby reducing the split tensile strength of the concrete

**Keywords:** self-compacting concrete, recycled coarse aggregate, compressive strength, split tensile strength, slump

# THE EFFECT OF THE USE OF RECYCLED COARSE AGGREGATE ON THE PERFORMANCE OF SELF-COMPACTING CONCRETE (SCC) AND ITS APPLICATION

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Received date 23.02.2022

Accepted date 03.04.2022

Published date 29.04.2022

**How to Cite:** Suryadi, A., Qomariah, Q., Susilo, S. H. (2022). The effect of the use of recycled coarse aggregate on the performance of Self-Compacting Concrete (SCC) and its application. *Eastern-European Journal of Enterprise Technologies*, 2 (6 (116)), 41–47. doi: <https://doi.org/10.15587/1729-4061.2022.255266>

## 1. Introduction

The development of concrete technology is getting faster day by day, along with various problems that arise during construction work. Various kinds of research have been carried out to obtain a better quality of concrete in terms of compressive strength, workability, ability according to needs, resistance to weather changes, resistance to fire and corrosion. However, concrete has various weaknesses, including low tensile strength and sometimes difficult workmanship. Self Compacting Concrete (SCC) is self-compacting concrete with a fairly high slump. SCC has high flowability to flow, fill the formwork, compact itself, and maintain resistance to segregation [1]. Segregation is the separation of various materials in the concrete mix. It means that coarse particles separate from the concrete mixture. Segregation resistance is significant for SCC, as low segregation resistance results in poor deformability and non-uniform clogging around reinforcement and concrete [2]. There have been many studies on SCC with different review factors, flowability, and durability to get maximum results.

Meanwhile, to meet the very large SCC coarse aggregate, a substitute material is needed that can be almost the same. As an alternative, it can use recycled coarse aggregate. Recycled coarse aggregate is obtained from construction waste, demolition of unused buildings, and the rest of ready-mix concrete. The factor that affects the quality of recycled coarse aggregate is the remaining mortar bond because this affects the absorption, density and abrasion values, causing the quality of the concrete to decrease [3]. Therefore, research conducted on recycled concrete continues to grow. Some studies were conducted to maximize the quality of recycled aggregates to be used optimally for SCC.

The utilization of recycled aggregate will reduce the quality of concrete because of the high porosity. One way to cover the voids or pores between the aggregate particles is to add a filler [4]. [5] conducted an experimental study in which the recycled aggregate contains 25 to 45 % mortar for coarse aggregate and 70 to 100 % for fine aggregate. The content of the mortar causes the specific gravity of the aggregate to be smaller, more porous or porous so that the hardness is reduced, the interface area is increased, and aggressive

chemical elements enter and damage more easily. Additional materials are intended to improve and increase the material's properties under the desired concrete properties. Additional materials used in concrete can be divided into two, namely chemical additives or chemical admixtures, and mineral additives are known as additives. Additive additives are added to improve the performance of the strength of the concrete, while the admixture facilitates workability, which is added during mixing and casting [6].

Some differences in quality, physical and chemical properties of recycled aggregates resulted in decreased compressive strength, tensile strength, and modulus of elasticity of concrete. As a result, there is a slope of the uniaxial stress-strain relationship curve, gentle before the peak load and steep after the peak load. In addition, the multiaxial peak stress-strain relationship decreases [7].

However, no one has discussed the performance analysis of self-compacting concrete using recycled coarse aggregate in previous studies. The performance analysis in question is the behaviour of concrete testing, which includes the compressive strength of concrete and the split tensile strength of concrete.

Therefore, studies that are devoted to the development of SCC concrete with lower strength than normal concrete scientific relevance. It is to obtain SCC concrete by utilizing waste, thus helping to protect the environment and lower costs. One of the possible concrete products is previous concrete. The previous concrete was concrete that was able to flow water on its surface directly to the layer below it, because its structure had pores between the aggregate bonds, making it suitable for road concrete.

In addition, the studies that are also devoted to the use of waste concrete as an SCC material scientific relevance. It is because the concrete waste still has material properties as an aggregate. So that the utilization of construction waste is very possible as a concrete mixture. For the reason, it is necessary to study the performance of using residual concrete as coarse aggregate in self-compacting concrete.

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## 2. Literature review and problem statement

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The main difference between SCC and conventional concrete lies in the composition of the concrete mixture, namely the use of a fairly large portion of the filler, about 40 % of the total volume of the concrete mixture. The filler is fine-grained sand with a maximum grain diameter ( $d_{max}$ ) of 0.125 mm [8]. The large portion of the filler causes the concrete mixture to behave as a paste. The difference between the proportions of the SCC mixture and the conventional mixture lies in the amount of coarse aggregate and powder to cement. The powder is cement combined with other pozzolanic materials, fly ash, and silica fume. In addition, SCC also uses admixtures in the form of superplasticizers [9].

The use of waste concrete as a substitute for coarse aggregate affects compressive strength. The compressive strength tends to decrease along with the increase in the percentage of the aggregate of waste concrete, and the use of waste concrete also affects the value of the modulus of elasticity. The modulus of elasticity also tends to decrease, and the increase in percentage of concrete waste aggregate [10].

The water-cement factor also affects the strength of concrete and the ease of working concrete. The lower the f.a.s

value, the higher the value of the compressive strength of the concrete. But in reality, if the f.a.s value is lacking in mixing, the concrete is difficult to compact. Thus, a certain f.a.s value can produce maximum concrete compressive strength. The concrete mix greatly affects the compressive strength of the concrete after it hardens. If the density of air pores is 5 %, the compressive strength of concrete will be reduced by 35 %, and if the density of air pores is 10 %, the compressive strength of concrete will be reduced by 60 % [11].

[12] conducted a study on the effect of fly ash on flowability and workability. In this study, the water-cement factor was 0.41, the maximum size of the coarse aggregate was 12.5 mm, additional fines in the form of fly ash at a dose of 0 %, 10 %, 20 %, 30 % and 40 % of the weight of the binder and used Viscocrete-10 admixture with a dose of 1 % of the weight of the binder. Workability and flowability testing using slump cone test and L-shaped box test. The conclusion of this research is (1). The fly ash content on the flowability of fresh concrete. The more fly ash content, the slower the flowability of fresh concrete (2). The optimal variant of fly ash is used to get self-compacting concrete with the addition of 20 % fly ash.

[13] researched the utilization of glass powder as a powder in self-compacting concrete. This research uses glass powder as a substitute for cement weight. The glass powder used consisted of two types, namely glass powder that passed the No. sieve. 100 was retained on the No. 200 sieve (BSK $\phi$ 100– $\phi$ 200) and the glass powder passed the No. sieve. 200 (BSK $\leq$  $\phi$ 200) with 6 kinds of mixed composition 0 %, 10 %, 15 %, 20 %, 25 %, and 30 % glass powder by weight of cement. The study discusses slump flow, compressive and split tensile strength, flowability, and silica fume content. The conclusions of the study are (1). To achieve the slump flow value for self-compacting concrete of 50 cm, the maximum partial substitution of glass powder that can be done is 10 % of the weight of the powder (2). The optimum level of partial substitution of glass powder is 10 % (3). The addition of free water content can increase flowability but can decrease the value of the compressive strength and split tensile strength of the concrete (4). The silica fume content of 5 % is the optimum level to increase the compressive strength and split tensile strength.

[14] researched the physical and mechanical behaviour of self-compacting concrete (SCC) using volcanic ash as a cement substitute additive. The use of volcanic ash and lime ash used is 10 %, 15 %, 20 % and 25 % of the cement mass and also the use of 1 % superplasticizer from cementitious material. His research is related to workability properties, the effect of compressive and split tensile strength and the effect of superplasticizer. The conclusions of this study are (1). The amount of superplasticizer dose added affects the workability of SCC concrete when testing liquid concrete. The more doses of superplasticizer given, the greater the flowability, passing ability, and passing ratio (2). The effect of adding volcanic ash affects the magnitude of the compressive strength. The addition of 10 % and 20 % volcanic ash actually caused a decrease in strength but experienced an increase in compressive strength at the addition of 15 % volcanic ash content (3). The magnitude of the split tensile strength produced from SCC concrete using volcanic ash is 10 % $\pm$ 2.

[15] examined the Effect of Adding admixture on the Characteristics of Self Compacting Concrete (SCC). His research discusses the effect of superplasticizer on concrete. Superplasticizer variation of 1.5 %, 2 %, 2.5 % by reducing the water content of the mixture. The conclusions of this study are (1) that the addition of superplasticizer admixture affects the characteristics of SCC, namely the level of workability. (2) the greater the level of superplasticizer that is given, the higher the level of flow traceability as measured by the slump-flow SCC value.

The recycled coarse aggregate from the concrete waste is crushed by a stone crusher machine and sieved to obtain the desired aggregate. The aggregate obtained from the results of the crushing is not necessarily the actual aggregate. The recycled aggregate has different characteristics from the original aggregate [16]. It is due to the presence of other mixing materials contained in the aggregate grains, namely a layer of mortar attached to the aggregate. The mortar layer itself consists of the aggregate and cement paste used in the previous concrete mix. Therefore, it is necessary to first examine the characteristics of the recycled aggregate itself. [17] also said that concrete with used aggregate has higher flexural and tensile strength than normal concrete, and It is very advantageous when used in rigid pavement structures/pavements of roads and airports where these properties are the basis for planning.

On the other hand, demolition of buildings and civil infrastructure in the form of concrete produces concrete waste. In addition, the use of ready mix concrete is widely used for building construction, but in its application there is often an oversupply and the rest is sometimes dumped in any place, so that it can cause new problems. Concrete waste that is left without processing will cause its own problems for the environment. Disposal of waste concrete requires a cost and a place for disposal. Therefore, it is necessary to study the use of waste concrete as an SCC material, the problem is how the performance of concrete when using recycled coarse aggregate is needed.

### 3. The aim and objectives of research

The aim of research is identifying the influence use of recycled coarse aggregate on the performance of self-compacting concrete (SCC) for its application.

To achieve this aim, the following objectives have been set:

- identifying the effect of using recycled coarse aggregate on the performance of self-compacting concrete (SCC);
- identification of concrete product applications.

### 4. Materials and Methods

The materials used to make concrete are Portland cement, sand, gravel and water and recycled concrete as a substitute for coarse aggregate. The control variable used normal quality 25 MPa concrete (0 % recycled aggregate). Recycled concrete raw materials are obtained from construction waste and ready-mix concrete residue (Civil Engineering Laboratory of the Malang-Indonesian State Polytechnic). The composition of the concrete mix uses the American Concrete Institute standard (ACI 211.1-91) with a concrete quality of 25 MPa, as shown in Table 1.

Table 1

The composition of the concrete mix

Material	Recycled aggregate				
	0 %	25 %	50 %	75 %	100 %
Cement (kg)	7.25	6.2	6.2	6.2	6.2
Lime (kg)	0	1.09	1.09	1.09	1.09
Water (kg)	2.55	2.55	2.55	2.55	2.55
Fine aggregate(sand) (kg)	9.8	9.8	9.8	9.8	9.8
Coarse aggregate (gravel) (kg)	17.67	13.25	8.83	4.42	0
Recycled aggregate (kg)	0	4.42	8.84	13.25	17.67

The preparation stage for normal concrete work is mixing the concrete ingredients and then stirring in a concrete mixer. Furthermore, the aggregate wear test, aggregate hardness test, compressive strength test of concrete and tensile strength test was carried out. The wear test refers to the standard AASHTO T-96-74, ASTM C-131-55 and SNI 2417-2008 on how to test the wear and tear of recycled aggregate with the Los Angeles abrasion machine. The coarse aggregate wear standard according to ASTM C 33 1996 in this test, the maximum coarse aggregate abrasion value is 50 %, where according to SK SNI S 04 1989 for concrete quality B0–B1 is required 40–50 %, K 125– K 225 is required 27–40 % and for quality >K 225 required <27 %. Hardness testing of recycled aggregate refers to British regulatory standards. The test uses recycled coarse aggregate that has been washed so that the mud content is clean; after that, it is baked with the aggregate used, the aggregate that passes the 12.5 mm sieve and is retained in the 9.5 mm sieve. The test results will use the aggregate that is retained on a 2.36 mm sieve. The test object will be pressured 40 tons at a speed of 4 tons/minute. Testing the Compressive Strength of Concrete refers to SNI 03-1974-2011 on how to test the compressive strength of concrete with cylindrical specimens. The test uses a scale with an accuracy of 0.3 % of the weight of the concrete, a concrete press and a capping machine. At the same time, the split tensile strength test of concrete refers to SNI 03-2491-2014 regarding the method of testing the split tensile strength of concrete. The test was carried out at the design age of 7, 21 and 28 days with the shape of a cylindrical specimen. Variations of recycled aggregates start from 0 %, 25 %, 50 %, 75 %, and 100 %. For the planned compressive strength of 25 MPa.

### 5. Results of research on the performance of concrete using recycled coarse aggregate and its application

#### 5.1. Concrete performance test results

The indicators for concrete performance are the compressive strength and split tensile strength of concrete. However, before testing the compressive strength of concrete and split tensile strength, it is necessary to test to determine the characteristics of the aggregate. This test is needed to find out whether the recycled aggregate still meets the standards of concrete materials. The tests carried out include Fineness Modulus, specific gravity and absorption, moisture content, aggregate wear, and aggregate hardness. The test results are shown in Table 2.

Table 2

Test Results for Recycled Coarse Aggregate

Type of Test	Unit	Test Result	Standard	Reference	Description
Smoothness Modulus	-	5,66	5.0-8.0	ASTM C 136 - 01	Fulfill
SSD Density	gr/cm <sup>3</sup>	2,61	2.5-2.7	SNI 1970 - 2008	Fulfill
Absorption	%	2,37	1-5 %	SNI 1970 - 2008	Fulfill
Water content	%	1,99	1-5 %	SNI 03 - 1971 - 2011	Fulfill
Aggregate Wear	%	58,08	27-40 %	SK SNI S 04 - 1989 F	No Fulfill
Aggregate Hardness	%	5,26	<40 %	SNI 03 - 2417 - 1991	Fulfill

Table 2 shows the results of testing for fine modulus, SSD specific gravity, absorption, and moisture content, as well as aggregate hardness that meets the standard requirements. On the other hand, aggregate wear does not meet the requirements of concrete standards. The magnitude of the wear value is thought to be because the recycled aggregate is not resistant to friction and has a surface that tends to be porous.

In addition, prior to testing the compressive strength of concrete, to determine the weight ratio of each variation of concrete, a concrete cylinder weight test was carried out. The results of the Concrete Weight Test are shown in Table 3.

Table 3

Concrete weight

Recycled coarse aggregate mix	Heavy (Kg)
0 %	12.916
25 %	12.303
50 %	12.294
75 %	12.157
100 %	12.027

Table 3 shows the weight of the test object using natural coarse aggregate is 12,916 kg, while the specimen using recycled concrete is 25 %, 50 %, 75 % and 100 %, the weight of the test object is 12,303 kg, 12,294 kg, 12,157 kg and 12,027 kg.

This shows that the weight of the concrete decreases with the increase in the percentage of recycled coarse aggregate mixture. This is because it is influenced by the weight of recycled coarse aggregate at each percentage of the mixture. The greater the percentage of the mixture, the more mortar in the recycled coarse aggregate. So it affects the quality of concrete solids, and the weight of the concrete is getting lighter.

While the test results of the variation of the percentage of recycled aggregate on the compressive strength of concrete at the age of 28 days, as shown in Fig. 1.

Fig. 1 shows that the percentage of recycled aggregate affects the compressive strength of concrete. The average compressive strength of the specimens using recycled aggregates of 25 %, 50 %, 75 % and 100 % were 18,825 MPa, 18,684 MPa, 16,561 MPa and 15,711 MPa. The test object without using recycled aggregate is 20,124 MPa.

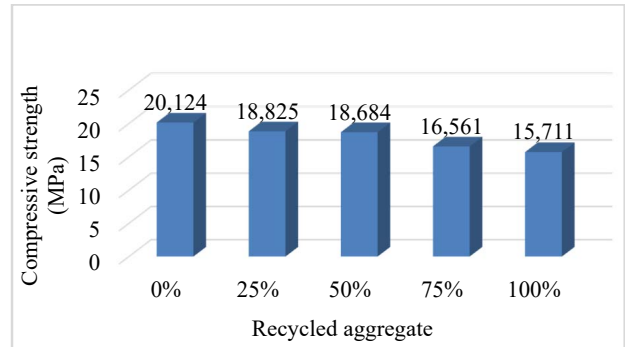


Fig. 1. Compressive strength of concrete, aged 28 days

When the weight of the concrete cylinder is reduced, the increase in recycled coarse aggregate causes the bonding of the concrete mixture to decrease. This causes the compressive strength of the concrete to decrease. In addition, from the results of testing the compressive strength of concrete, it can be seen the shape of the cracked concrete pattern. There are two types of concrete crack patterns, namely shear and parallel to the vertical axis (column). The shape of the crack pattern of the test object can be seen in Fig. 2.

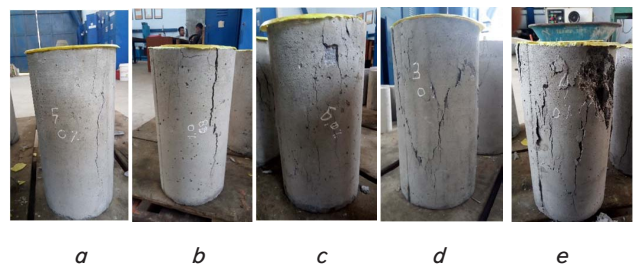


Fig. 2. Crack pattern of compressive strength test: a - 0 %; b - 25 %; c - 50 %; d - 75 %; e - 100 %

Fig. 2 shows the crack pattern of concrete with recycled aggregate (25 %) and (50 %) in the form of shear. It shows the bond between mortar and aggregate is quite strong, compared to 75 % concrete and 100 % recycled aggregate, which has a crack pattern parallel to the vertical axis (column). While the results of the split tensile test used a cylindrical test object with a diameter of 15 cm and a height of 30 cm, the test results were carried out when the concrete was 28 days old, as shown in Fig. 3.

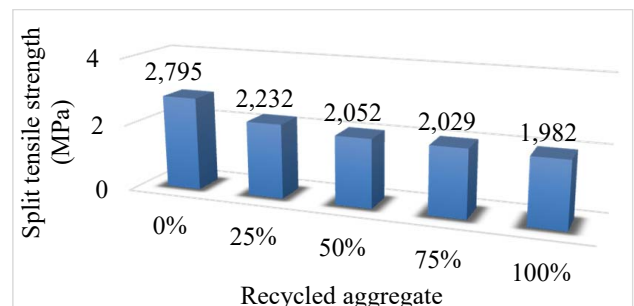


Fig. 3. The split tensile strength of concrete, aged 28 days

Fig. 3 shows the value of the split tensile strength of concrete with a variation of 0 % recycled coarse aggregate of



2,795 MPa, 25 % of 2,232 MPa, 50 % of 2,052 MPa, 75 % of 2,029 MPa and 100 % of 1,982 MPa.

The value of the split tensile strength of concrete shows the bonding relationship between the mortar mixture. With an increasing variety of recycled aggregate, the split tensile strength of concrete decreases. The decrease was caused by the weak bond between the recycled aggregate and the mortar. Concrete with recycled aggregate has a surface that is prone to cracks and cavities. If the split tensile test is carried out, the concrete will collapse easily. Meanwhile, normal aggregate has a good mortar binding capacity because the surface of natural coarse aggregate tends to be rough and porous, making it easier to bind aggregate with mortar. It is also proven visually in the split tensile strength test of concrete, as shown in Fig. 4.



Fig. 4. Concrete Visual Differences: a – natural aggregate; b – recycled aggregate

Fig. 4 shows that concrete with natural coarse aggregate has a characteristic brownish colour, slightly white in colour with a high hardness value. Meanwhile, concrete with recycled coarse aggregate has many cracks and voids.

### 5. 2. Identification of concrete product applications

The application of concrete products is not only based on compressive strength and split tensile strength but also based on the results of the slump test. The results of the slump test for the recycled coarse aggregate variation are shown in Fig. 5.

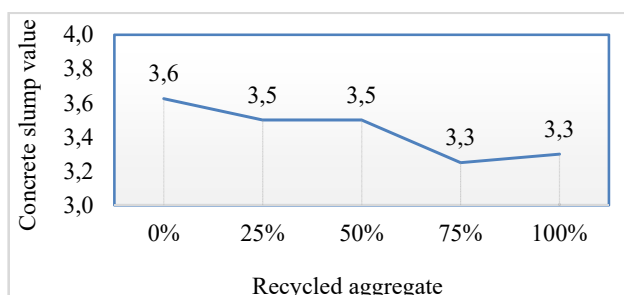


Fig. 5. Concrete Slump Test Value

Fig. 5 shows the Slump Test value for recycled aggregate with a variation of 0 % by 3.6 cm, for a variation of 25 % for aggregate 3.6 and 50 % by 3.5 cm, and for an aggregate variation of 75 % by 3.3 cm. And for the aggregate variation of 100 % – 3.4 cm. The results of the four Slump Tests show that they have met the requirements for the planned Slump value of 36 cm. The highest Slump value is found in the 0 % variation and 25 % variation. The lowest slump was found in the aggregate variation of 75 % with

the addition of 0.5 kg of water. This is due to the difficulty of the concrete mixing process. The higher the value of the implementation phase, the higher the slump value, resulting in a lower compressive strength value, and the concrete properties are the same as the characteristics of porous concrete. Porous concrete is very suitable for use as non-structural concrete, for example, road shoulders. Good non-structural concrete has compressive and tensile strength values, is resistant to weather and chemical influences, and does not seep. The tensile strength and bonding strength of concrete are generally 10 % of the compressive strength value.

## 6. Discussion of experimental results on concrete performance using recycled coarse aggregate

Table 2 shows that the recycled aggregate has a high wear value, so it is porous. So unable to withstand and porous. This causes the mixture to separate easily. This makes the weight of the concrete lighter (according to Table 3).

Fig. 1 shows the difference in compressive strength values between normal concrete and concrete using recycled aggregate. It can be seen that normal concrete has a compressive strength of 20,124 MPa, while concrete with recycled coarse aggregate is only 15,711 MPa. Concrete with the use of recycled aggregates experienced a decrease in compressive strength. The cause of the decline in the quality of concrete is due to differences in the physical properties of recycled aggregates with natural aggregates – the differences in the properties of concrete materials that affect the quality of concrete. Recycled coarse aggregate requires more water than natural aggregate. Because recycled coarse aggregate has greater water absorption properties than natural aggregate, this causes the cement factor value is inconsistent. Recycled aggregate also contains used mortar, where the mortar contributes to the bond strength of the concrete mix.

Fig. 2 shows the fracture pattern of the specimen in the recycled coarse aggregate mixture. Fig. 2, b, c failure begins with shear cracks, then continues with increasing strain. Cracks occur due to workload in the middle of the concrete span. At workload initially, shear cracks occur in the middle span so that it can cause concrete collapse. With increasing load, shear cracks increase in size and length and other shear cracks until the test object is declared to have collapsed. Fig. 3, d, e show the crack pattern (columns) vertically. The number of cracks is more than normal concrete (Fig. 3, a). Crack patterns parallel to the vertical axis occur at one-third and two-thirds of the span length. With increasing load, the crack increases in size and length and other cracks until the test object is declared to have collapsed.

Fig. 3 shows that with increasing variations of recycled coarse aggregate from 0 %, 25 %, 50 %, 75 % to 100 %, the split tensile strength of concrete decreases. It is proven that the 0 % aggregate has a split tensile strength of 2.795 MPa while the 100 % aggregate is 1.982 MPa. Because the more aggregate is mixed, the weaker the bond between the aggregate and the mortar, and voids and cracks appear in the concrete (Fig. 5). The lack of adhesion is due to mortar marks adhering to the aggregate. In

addition, the decrease in split tensile strength of concrete was also caused by the difference in quality between the recycled concrete coarse aggregate and natural coarse aggregate, including the wear rate of the recycled concrete aggregate. The value of the split tensile strength of concrete is strongly influenced by the quality of the coarse aggregate used. Meanwhile, recycled coarse aggregate is obtained from the breakdown of concrete waste so that its quality is lower than natural aggregate.

This study develops SCC concrete at a lower cost than the use of natural aggregates. From these properties, waste concrete can provide advantages when used as an aggregate substitute for natural aggregate in SCC concrete mixtures. Because the test results show that SCC concrete using recycled coarse aggregate is porous, it is not suitable for structural concrete but can be applied to non-structural concrete (such as road boundaries, pavements, landscapes, and the like). It can be seen that the slump test value, the greater the percentage of recycled coarse aggregate, the lower the slump value. The decrease in the slump value causes the workability of the concrete to be low, so that the concrete becomes porous and reduces its performance of the concrete.

The research limitation is that the concrete compressive strength used is 25 MPa. The concrete test results for the function of the column and beam building so that the Slump value used is 3.0 6.0 cm. The test object used a cylindrical mould with a diameter of 15 cm and a

height of 30 cm. Moreover, the compressive strength test was carried out when the concrete was 7, 21 and 28 days old, while the split tensile strength test of the concrete was only at the age of 28 days. The development in the research is to make concrete with low cost but to make high-quality concrete.

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## 7. Conclusions

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1. The use of recycled aggregate in the SCC concrete mixture reduces the performance of the concrete. It is indicated that the compressive strength of the concrete in the 0 % aggregate mixture is 20,124 MPa, while in the 100 % aggregate mixture, it is 15,711 MPa. In contrast, the value of split tensile strength at 0 % aggregate mixture is 2.795 MPa, while at 100 % is 1.982 MPa.

2. Application of SCC concrete with the recycled coarse aggregate mixture is very suitable for non-structural concrete, as evidenced by the slump value at 0 % aggregate mixture is 3.6, while at 100 % it is 3.3.

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## Acknowledgement

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We want to thank the State Polytechnic of Malang for funding the research to completion.

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