The experimental compressive strength of normal and self-compacting concrete with recycled coarse aggregate

D Nuralinah\(^1\), E Arifi\(^1\) and D Setyowulan\(^1\)

\(^1\) Civil Engineering Department, Brawijaya University, Jl. MT. Haryono 167 Malang, East Java, Indonesia

devi@ub.ac.id

Abstract. Self-Compacting Concrete (SCC) is an innovation in the technology of making concrete that does not require a compaction process to fill the formwork. In this study, recycled coarse aggregate (RCA) was used as constituent material in both normal and SCC concrete. The aggregate was obtained from ready mix concrete waste with the quality of K300–K350, which was crushed into a size of 5-10 mm (25%) and 10-20 mm (75%). Concrete was cast into concrete cylinders, size of 15x30 cm then treated and tested at 28 days. In SCC concrete, superplasticizer is used, but fly ash was not used in the concrete mixture. The compressive test results show that normal concrete has a higher compressive strength than self-compacted concrete. This is due to the high amount of coarse aggregate that used in normal concrete. The results are almost corresponding with modulus of elasticity.

1. Introduction

The need for concrete material is increasing along with the many construction developments. The utilization of resources, such as gravel becomes larger. Massive natural stone mining causes environmental damage. With the increase in the need for concrete, making the constituent materials from nature experience over-exploitation and also the use of unbalanced natural resources, causing the material constituent of concrete to rise in price.

This material was chosen as an alternative of natural aggregate due to a large amount of waste from building destruction that was dumped carelessly. Partial disposal of waste are used as waste material and some is disposed of in open fields. Improper use of waste will cause damage to the environment. Used construction waste that has high-quality concrete can be managed into new aggregates of different qualities and can be used as recycled coarse aggregate (RCA).

In addition to environmental problems, one of the problems in concrete production is the lack of skilled workers in this field. As a solution, in the early 1980s, Japan began to develop SCC (self-compacting concrete) concrete. This concrete was widely used in the early 1990s, SCC is concrete that has high flowability and can fill concrete mold spaces without compaction or only requires a small amount of vibration to compact them. In the implementation of construction, the construction of concrete SCC can be applied with a smaller number of workers, so that the costs incurred also become more efficient.

The main difference between SCC and conventional concrete is the composition of the concrete mixture, where the portion of the filler is quite large, about 40% of the total volume of the concrete mixture. This filling material is fine-grained sand with maximum grain size is less than 0.125 mm.
Large portions of this filler cause concrete mixtures tend to behave as pasta [1].

Figure 1. Comparison of SCC and normal concrete mixture proportions (Okamura and Ouchi, 2003)

From Figure 1, it can be seen that the difference in the proportion of the mixture between SCC concrete and normal concrete is the amount of coarse aggregate (G) and the amount of powder (P) to cement (C). Powder is cement which is combined with other fine particles (grain size <0.125 mm) such as fly ash and silica fume. In addition, admixture is used in SCC such as superplasticizers. There is no significant difference in the amount of water (W) and sand (S) [1].

The SCC concrete compressive strength test results showed that recycled coarse aggregate could reduce the compressive strength by 12.26% when natural stone aggregates were used (from 50.74 MPa to 44.52 MPa). However, when combined with round natural aggregates, the compressive strength increased by 62.78% (from 27.35 MPa to 44.52 MPa) [2].

In this study, the use of recycled coarse aggregate was used not only in normal concrete but also in self-compacting concrete. So it is necessary to test the compressive strength to determine the characteristic of material, such as the modulus of elasticity.

2. Experimental methods
Cylindrical specimens, whose size is 15cm x 30 cm, were made from a mixture of normal concrete and self-compacting concrete, with 100% recycled aggregate composition. The aggregate was obtained from ready mix concrete waste with the quality of K300-K350, which was crushed into a gradation of 5-10 mm (25%) and 10-20 mm (75%). The use of gradations based on the results of the sieve analysis aims to produce homogeneous and aggregate interlocking in concrete. Before the manufacture of cylinder test material, aggregate analysis which included analysis of water content, analysis of specific gravity in SSD conditions, analysis of content weight and the aggregate absorption were carried out. The mix proportion of both normal and self-compacting concrete is explained in Table 1.

| Type of concrete       | Cement (kg) | Water (kg/lt) | Fine aggregate (kg) | Coarse aggregate (kg) | Admixture/Superplasticizer (%) |
|------------------------|-------------|---------------|---------------------|-----------------------|---------------------------------|
| Normal concrete        | 410         | 240.64        | 781.26              | 868.10                | -                               |
| Self-compacting concrete| 410         | 205           | 926.75              | 758.25                | 1                               |

In the self-compacting concrete, testing of the filling ability of the mixture with a slump flow was conducted after mix design. Slump test was carried out in normal concrete. Concretes were cast in the cylinder and after the formwork was removed, the specimens were cured and tested after 28 days. Research procedure of testing of specimen can be seen in Figure 2.
Table 2. Cylinder specimens

| No | Coarse aggregate | Type of concrete and specimen | Designed compressive strength | Admixture | Sample amount |
|----|------------------|------------------------------|------------------------------|-----------|--------------|
| 1  | RCA 100%         | Normal (BRCA)                | 20 MPa                       | -         | 6            |
| 2  | RCA 100%         | SCC (SBR)                    | 20 MPa                       | Superplasticizer (Viscocrete 3115) | 3            |

Figure 2. Research of procedures

2.1. Method of analysis
From the results of testing the compressive strength, elastic modulus can be analyzed based on changes in longitudinal displacement at each loading stage of 10 kN using an extensometer. The mechanical properties of concrete with recycled coarse aggregates will be compared to the use of normal concrete and self-compacted concrete.

In calculation of modulus of elasticity, it is compared with SNI standard and ACI standard for validation purpose. The equations of the modulus elasticity are as follows:

\[ E_c = \frac{S_2 - S_1}{\epsilon_2 - 0.0005} \]  \hspace{1cm} (1)

\[ S_2 = 0.4 \times f'c \]
\[ S_1 = \text{strength when } \varepsilon_1 = 0.00005 \text{ (obtained from regression curve of experimental strength-strain)} \]

\[ E_c = 0.043 \times W_c^{-1.5} \times f'_c^{0.5} \text{ (SNI-T-15-1991)} \]
\[ E = 4730 \times \sqrt{f'_c} \text{ (ACI 318-89)} \]

3. Results and discussions

From aggregate testing, the results of water content, content weight, specific gravity and absorption of recycled coarse and fine aggregates were obtained, as seen in Table 3. Besides that, the results of testing the physical properties of fresh concrete and hard concrete can be obtained.

3.1. Results of aggregate examination test

| Examination                        | Recycled coarse Aggregate | Fine aggregate |
|-----------------------------------|---------------------------|----------------|
| Water content (%)                 | 5.09                      | 4.37           |
| Weight of content in rodded (gr/cc) | 2500.78              | 2436.33       |
| Weight of content in sholeved (gr/cc) | 2230.08             | 2075.39       |
| Density                           | 2.44                      | 2.48           |
| Absorption (%)                    | 2.73                      | 6.79           |

3.2. Test results for the physical properties of fresh concrete

3.2.1. Slump height or slump flow test.
In normal concrete, a slump test was carried out to determine homogeneity and workability of mortar in fresh concrete with certain viscosity expressed by a slump value. In this research, the designed slump value was between 7 cm-15 cm. While, slump flow for testing of self-compacting concrete must have a good filling ability, which was designed between 60-85 cm. The slump height or slump flow test results can be seen in Table 4.

| Specimens | Mixing variation | Slump height or flow | Average |
|-----------|------------------|----------------------|---------|
| BRCA-1a   | Normal concrete-RCA | 14 (slump height)   | 14.33 (slump height) |
| BRCA-1b   | Normal concrete-RCA | 14 (slump height)   |         |
| BRCA-1c   | Normal concrete-RCA | 15 (slump height)   |         |
| SBR-1     | SCC-RCA           | 63 (slump flow)      | 61 (slump flow)    |
| SBR-2     | SCC-RCA           | 58 (slump flow)      |         |
| SBR-3     | SCC-RCA           | 62 (slump flow)      |         |

3.3. Test results for physical properties of hard concrete

3.3.1. Compressive test result.
Results of cylindrical compressive test can be seen in Figure 3.
Figure 3 shows that the compressive test of normal concretes is higher than that of self-compacting concrete. Regarding the mix proportion in Table 3, it can be explained that the compressive test of normal concrete is significantly affected by the high amount of coarse aggregate.

Figure 4. Relationship between strength and strain of normal concrete with recycled coarse aggregate

Figure 5. Relationship between strength and strain of self-compacting concrete (SCC) with recycled coarse aggregate
In Figure 4, normal concrete with recycled coarse aggregate (specimen BRCA-1a) results the highest compressive stress of 38.46 MPa with a deformation value of 0.0015 mm. While, in self compacting concrete with recycled coarse aggregate (SBR-2a specimen), the maximum compressive stress value is 31.11 MPa and deformation is 0.0014 mm, as shown in Figure 3.3.

Therefore, the compressive test of normal concrete is higher than the compressive test of self-compacting concrete, corresponding with the strain value. It might be caused there is no cement substitute using, such as fly ash that used in the SCC concrete, and high amount of coarse aggregate that used in the normal concrete.

According to the concrete compressive test results, calculated elastic modulus of each specimen can be obtained and compared each other with SNI and ACI standard specifications, as seen in Table 5.

Table 5. Modulus of elasticity of specimens

| No | Specimens  | Calculated elastic modulus (MPa) | Averaged elastic modulus (MPa) | Elastic modulus of SNI code (MPa) | Elastic modulus of ACI code (MPa) |
|----|------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|
| 1  | BRCA-1a    | 36793                           |                                 | 35789.25                         | 29316.32                         |
| 2  | BRCA-1b    | 35152                           |                                 | 25174.25                         | 23709.36                         |
| 3  | BRCA-1c    | 29495                           |                                 | 21715                            | 20813.64                         |
| 4  | BRCA-1c1   | 41717                           |                                 | 28245                            | 26488.01                         |
| 5  | SBR-1      | 26280                           |                                 | 25174.25                         | 23709.36                         |
| 6  | SBR-2      | 24457                           |                                 | 25455.78577                      | 23709.36                         |
| 7  | SBR-3a     | 21715                           |                                 | 21715                            | 20813.64                         |
| 8  | SBR-3b     | 28245                           |                                 | 28245                            | 26488.01                         |

Table 5 shows that there is correlation between result of compressive strength and elastic modulus of concrete. Among the specimens, calculated elastic modulus of self compacting concrete specimens almost coincide with validation result based on SNI and ACI.

4. Conlusion

From research that explained above, it can be concluded that:

• The compressive strength of normal concrete is higher than that of self-compacting concrete.
• Modulus of elasticity of both normal and self-compacting concrete corresponds with compressive test results. Averaged elastic modulus based on calculation agree with validation result based on SNI and ACI standard specification code.

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