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The Role of Recycling Waste Powder as a Sustainable Concrete Manufacturing Material

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Abstract. The production of high-quality recycled aggregate from waste concrete provides a by-product in the form of a powder. It has been separated from the surface of the aggregate during a grinding process. The properties of the powder and its application as a material in the manufacture of concrete were investigated in this study. It is expected that this powder waste can be used sustainability in concrete manufacturing. The testing procedure included an investigating of the chemical, physical, and mechanical properties of the concrete waste powder. Furthermore, the powder was used both as a substitute for Portland cement by 25% and 50% and as an addition of Portland cement by 5%. The initial setting time, final setting time, and the consistency of the recycled waste concrete powder are greater than that of Portland cement. The increase also occurs in the chemical content of iron oxide. Furthermore, concrete with a substitution of 25% and 50% of waste concrete powder shows a decrease in compressive strength of 23.54% and 42.84%, respectively, compared to the normal compressive strength. Meanwhile, the addition of concrete waste powder to concrete with an addition of 5% reaches an increase in compressive strength of 22.98%. The use of waste concrete powder is recommended as an additional material because it can perform as filler; consequently, it produces denser concrete.

INTRODUCTION

Concrete is a construction material widely used in building structural work because of its many advantages, including the constituent materials that are easy to obtain, easy to form, cheaper, do not require special treatment, and are more resistant to the weather [1]. Almost all the materials used for the manufacture of concrete use materials from nature so that with the use of large concrete, massive mining of natural rock as a concrete-forming material occurs; as a result, the production of concrete is becoming more expensive. Furthermore, the high demand for cement in the manufacture of concrete is one of the background problems in the current construction industry. It is known that excessive use of cement is one of the things that cause global warming. Therefore the reuse of waste as a substitutive and additive material of Portland cement is essential [2], [3].

Another issue arising is that the demolition of concrete construction due to aging causes considerable concrete waste [4]–[7]. Recycling concrete waste is an alternative in reducing the negative impact of the accumulation of concrete waste on the environment. Extracting coarse aggregate from the concrete waste lump is a method to produce recycled aggregate. Higher quality recycled aggregate demands a clean surface from the surrounding old mortarr [6], [8]–[13]. Therefore, during the production process of higher quality recycled aggregate, a large amount of powder has been generated as the a-side product.

Several researchers have conducted a study on waste concrete powder [14]–[17]. In [16] using waste concrete powder in cement mortar. It was found that the compressive strength of the mortar became lower when a higher amount of waste concrete powder was used as a cement substitute. The compressive strength of mortar with powdered waste concrete is reduced by up to 73% compared to the mortar with Portland cement. A similar result has been found

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in other research on the cementitious properties of this concrete waste powder. Some components in the waste concrete powder are non-reactive so they cannot effectively act as cement. However, for the sake of the environment, research continues to be developed to be used as a material for making new concrete. Thus, this research will comprehensively study the properties of this waste concrete powder and its application to materials, either as a substitute for cement or as an additive in concrete mixtures. The concrete waste powder, which is a by-product of recycled aggregates with the thermal-mechanical method developed at the structure laboratory of the University of Mataram can considerably be used as an ingredient for sustainably concrete[10], [11].

THEORY

Waste Concrete Recycling Process

The conventional process of recycling concrete is breaking the large concrete lump into smaller pieces to produce coarse recycled aggregate. However, due to a large amount of attached mortar, the utilization has not been well developed. Along with the development of technology, recycling concrete is also developed using several methods. All the methods have been dedicated to obtaining higher quality of recycled aggregate free from the old cement paste in the surfaces. One of the waste concrete recycling methods is using a combination of heating and grinding methods.

Heating at a temperature of 100º C is intended to achieve evaporation of water contained in the pores of the mortar; therefore, it causes pressure in the mortar which facilitates the release of the mortar from the aggregate [18]. Then the heated concrete is brought into the grinding process. Grinding is effective for breaking the concrete and separating the attached mortar from recycled concrete. This method is usually carried out with a machine that rotates at a certain speed so that this rotation is intended to assist the release of mortar in the aggregate [11].

During the manufacturing process of higher quality recycled aggregate, 15-30% of powder waste is generated [14]. To be able to utilize this powder waste, further research is needed because so far, research on concrete waste has focused more on the production of recycled aggregates.

Physical Properties Testing

Physical test of concrete waste powder involves testing of normal consistency and setting time. The testings are conducted by performing a Vicat test. A normal consistency test is aimed to obtain the appropriate water content in a mixing. The normal consistency is greatly influenced by the amount and type of cementitious material used. Normal consistency is achieved when the Vicat needle can penetrate the paste 10 ± 1 mm within 30 seconds after needle removal. The setting time test was carried out by determining the penetration time obtained by 25 mm for the initial setting time. Meanwhile, the final setting time is when the needle does not appear to be immersed in the paste.

The initial setting time on ordinary Portland cement is required not less than 60 minutes, and the final setting time is not more than 480 minutes.

A reasonably long initial setting time is needed to allow the concrete maker to work on the concrete manufacturing process, namely mixing, pouring, compacting, and leveling the surface. For a shorter setting time, it is intended to provide faster hardening of the concrete so that construction work can be completed more quickly due to the more straightforward drying process [18], [19].

Mechanical Properties Testing

To investigate the mechanical properties of concrete is mainly through testing under a compression load. In this testing, the modulus elasticity of concrete can also be determined. According to SNI 03-1974-1990 [21], the compressive strength of concrete is the maximum magnitude of the compression load per unit area, which causes the concrete cylinder specimen to be a failure. A compression testing machine generates the compressive load with a load rate of 0.2 MPa/second. The maximum compressive strength f'c is given by Eq. 1:

$$\sigma = \frac{P}{A} \tag{1}$$

Where σ is compressive strength (MPa), P is the maximum compression load (N), and A is the cross-section of cylinder concrete (mm^2).

The modulus of elasticity of concrete is determined by dividing the stress by the strain during an elastic area. The condition is determined when the stress reaches 40% of the compressive strength. The equation of the modulus of elasticity according to the code is presented in Eq. 2 [20].

$$Ec = \frac{S_2 - S_1}{\varepsilon_2 - 0{,}00005} \quad (2)$$

Where E_c is modulus of elasticity (MPa), S_2 is stress at $0.4f'_c$, S_1 is stress at strain due to of 0.00005 (MPa), and ε_2 is strain due to stress S_1.

METHODOLOGY

Material

The concrete waste powder was generated from the production of recycled aggregate using the heating and grinding method. Preparation of the waste concrete powder material begins with cutting the waste concrete into approximately 20-30 cm. These pieces are put in an oven for 24 hours at a temperature of 100 C. This process is intended to weaken the bond of cement paste to the aggregate surface. In hot conditions, this concrete waste is taken to a crushing machine to get aggregates that are of appropriate size and free from cement paste. The remaining cement paste in the form of powder is under the machine and collected for use in this study. Furthermore, the powder is checked for fineness to match the requirements as a pozzolan, namely passing on a No 200 sieve with the amount of material passing more than 70%. This process is shown in Figure 1.

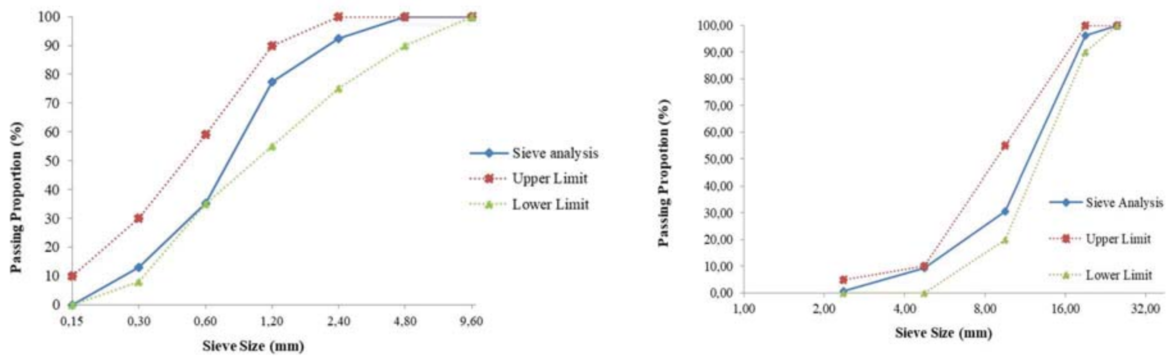
FIGURE 1. Waste concrete generation during recycled aggregate production

The waste concrete powder is utilized in concrete by using it as a substitute for cement and an additive to the concrete mixture. As a substitute for cement, percentages of 25% and 50% were used because it is desirable to use waste material as much as possible to benefit the environment. As much as 5% of the powder was used in the concrete mix as an additive. Concrete specimens with a binder of 100% Portland cement and 100% concrete waste powder were also prepared as control specimens. The variation of the test object is shown in Table 1.

TABLE 1. Specimens variation

Semen Type	Role	Proprotion in Concrete Mixture (%)
Portland Cement		100
Recycling	Subtitutive	25
		50
		100
	Additive	5

Fine aggregate and coarse aggregate used in concrete mixtures had a maximum diameter of 4.75 mm and 20 mm. Fine aggregate is natural aggregate, and coarse aggregate is crushed stone. The specific gravity of fine aggregate and coarse aggregate were 2.82 and 2.76, respectively. The properties of aggregates met the requirement from the national code of aggregate for concrete [21]. The results of the sieve analysis of the aggregates used can be seen in Figure 2.



a. Fine aggregate
b. Coarse aggregat

FIGURE 2. Sieve analysis

The calculation of the mixed design is based on the national standard SK.SNI.T-15-1990-03 with the water-cement factor value set at 0.5. The need for control concrete with 100% Portland cement is shown in Table 3. Furthermore, the need for waste concrete powder is proportional to the weight of Portland cement based on the percentages that have been set in Table 1.

TABLE 2. Concrete mixture proportion

Concrete Ingredients	Proportion (kg/m^3)
Water	225
Portland cement	450
Fine aggregate	817
Coarse aggregate	959

Testing

The test consisted of two aspects, namely testing of waste concrete powder material and testing of concrete specimens. Testing waste concrete powder includes testing on chemical composition, testing for normal consistency, testing for initial setting time, and testing for final setting time. Tests on concrete specimens included testing the properties of fresh concrete and the mechanical properties of concrete. For the mechanical properties testing, the concrete specimens were cylindrical in sizes 150 mm and 300 mm. The mechanical properties of concrete were investigated through compressive strength and elastic modulus. Figure 3-4 shows the intended concrete test.

FIGURE 3. Fresh properties of testing concrete

a. Some of the specimens b. Compressive testing

FIGURE 4. Specimens and concrete testing

RESULT AND DISCUSSIONS

Chemical Composition

From testing the chemical compounds' content on cement and concrete waste powder, the percentage of iron compounds (Fe_2O_3) in concrete waste powder is 3.23% compared to Portland Composite Cement (PCC) 2.91%. The content of iron (Fe_2O_3) in cement and powdered concrete waste has met the specified percentage value, which is 0.5%-6% [1].

The increase in the iron oxide content (Fe_2O_3) in the concrete waste powder is due to the cement, sand, and crushed stone in the recycled concrete waste still containing iron (Fe_2O_3). In the grinding process, they are combined into a constituent of concrete waste powder resulting in higher iron oxide content. As for the function of iron (Fe_2O_3) itself in cement, is as a forming compound of Tetracalcium Aluminoferite (C_4AF) or $4CaO.Al_2O_3.Fe_2O_3$. The C_4AF compound has a more negligible effect on the hardness of cement or concrete. Its contribution to the increase in strength is small. However, it has sufficient or moderate heat hydration so that it hydrates quickly.

Physical Properties

There was an increase in the need for water as the increasing proportion of powdered concrete waste as a substitute material. This is because the concrete waste powder absorbs more water during the mixing process. The consistency for Portland cement is found at 24.5%. Waste concrete powder requires 1.6 times more water to achieve normal consistency than Portland cement. As a substitute for 25% cement, waste concrete powder requires almost the same water as Portland cement with a normal consistency of 26%, as shown in Table 3.

TABLE 3. Normal consistency

Role	Proportion in Concrete Mixture (%)	Normal Consistency (%)
Portland Cement	100	24,5
Powder as Subtitutive	25	26
	50	31
	100	39
Powder as Additive	5	25,5

As an additive, waste concrete powder has a water requirement to reach a normal consistency of 25.5%. This amount is also not significantly different from the normal consistency of Portland cement. This is considered because the addition of concrete waste powder is relatively small at 5%. In order to maintain a consistent normal consistency in the increasing proportion of concrete waste powder as an additive, it is recommended to add a superplasticizer to the mixture.

Based on Figure 5, the initial setting time of Portland Cement is faster than that of waste concrete powder, in which an initial setting time of 105 minutes and a final setting time of 150 minutes. These values are increasing when the waste concrete powder is utilized as the binder entirely in the mixing. The initial setting time is increasing to 180 minutes and the final setting time escalates to 255 minutes. As seen from the graph, there is an increase in the initial and final setting time as the increasing use of waste concrete powder as a substitute material because the waste concrete powder has a lesser binding strength.

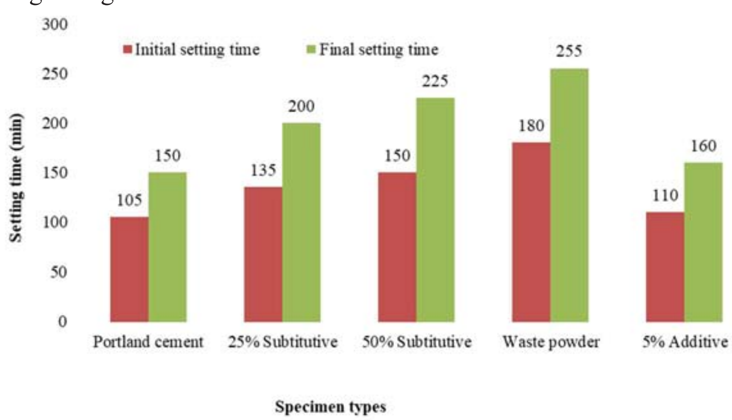


FIGURE 5. Specimens and concrete testing

Based on the test results of the setting time of Portland cement and waste powder, it shows that the two materials have met the requirements as a concrete mixture according to the requirements for the initial setting time on Portland cement not less than 60 minutes and the final bonding time should not be more than 480 minutes [1].

Fresh Concrete Properties

The greatest slump occurs on normal concrete with a Portland cement binder. The slump is 6.8 cm. This value drops to 4.5 cm when all portion of Portland cement is replaced by waste powder. The slump decreases to 11.76% and 23.53% in 25% and 50% substitutive of waste powder concrete, respectively. The lower slump value occurs on the concrete with waste concrete powder binder due to higher water absorption was occurring during the mixing.

The slump of the concrete with 5% waste powder as an additive gives a zero slump; however, to make it easier to work, a superplasticizer was added to the mixing. As the result, a slump of 7 cm is obtained.

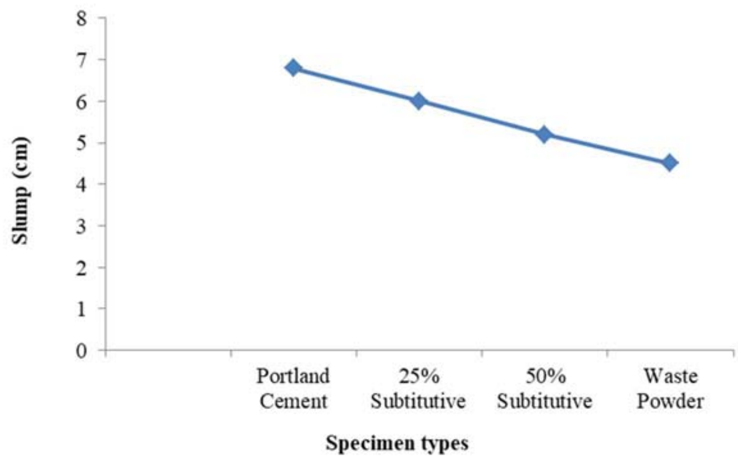
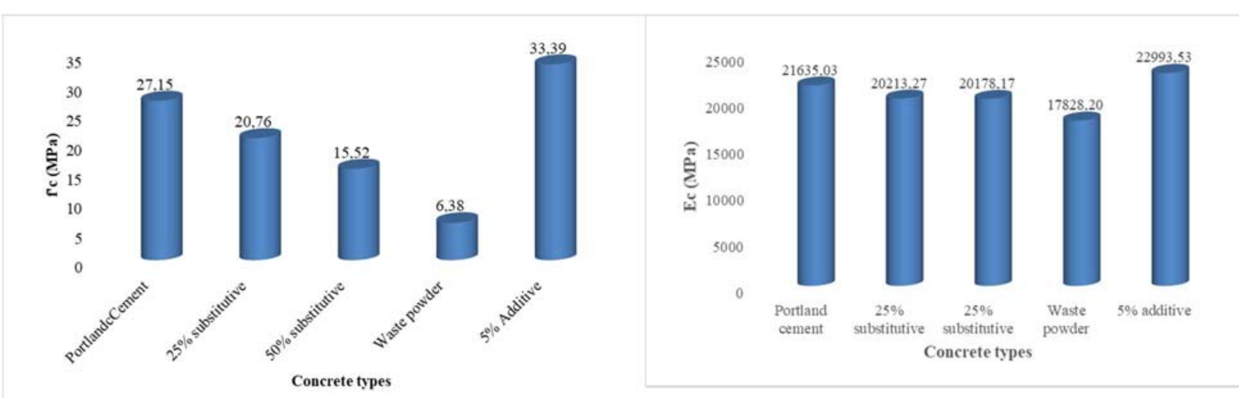


FIGURE 6. Fresh concrete slump

Mechanical Properties

Judging from the compressive strength of normal concrete of 27.15 MPa and concrete with a 25% waste powder compressive strength of 20.76 MPa, there is a decrease in compressive strength value by 23.54%. For the value of the compressive strength of concrete with a 50% waste powder mixture of 15.52 MPa, there is a decrease in the compressive strength value of 42.84%. The decrease is getting more remarkable for the entire waste powder used as the cementitious material in concrete. The decrease in the value of the compressive strength of concrete occurs because the waste concrete powder does not have a strong binding capacity like cement in general.

Meanwhile, the compressive strength value of concrete with waste powder as an additive material reaches 33.39 MPa, increasing the compressive strength by 22.98% from normal concrete. This is because the concrete waste powder as an added ingredient can fill the pores in the concrete so that the concrete becomes denser and the compressive strength value is high. Similar to compressive strength, the modulus elasticity is considered to have the same trend due to the role of the waste powder in concrete. Figure 7 shows the concrete mechanical properties.



a. Compressive strength

b. Modulus of elasticity

Figure 7. Mechanical properties

CONCLUSION

The concrete compressive strength test results show a decrease in each increase in the concentration of the mixed concrete waste powder as a substitute for cement used. For concrete with a mixture of 25%, 50%, and 100% waste powder, there was a decrease of 23.54%, 42.84%, and 76.50%, respectively, for normal concrete. In contrast, the waste powder as an added material by 5% experienced an increase of 22.98% against normal concrete.

The results of testing the modulus of elasticity of concrete are directly proportional to the compressive strength test results; the results show a decrease in each increase in the concentration of the waste powder mixture as a cement substitute. In the mixture with 25%, 50%, and 100% waste powder, the modulus of elasticity decreased by 6.57%, 6.73%, and 17.59%, respectively. Meanwhile, for waste powder as an added material, 5% increased by 6.28% compared to normal concrete.

The use of waste concrete powder as a substitute for cement does not increase the quality value of concrete, because the waste concrete powder does not have a strong binding capacity like cement in general. In comparison, the concrete waste powder as an additive material increases the quality value of concrete because the concrete waste powder can fill the pores of the concrete so that the concrete becomes solid.

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