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Effectiveness of vibratory added mixing concrete with heating-grinding recycled coarse aggregate

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Concrete is a building material that is widely used in the construction industry. With the increasing need for concrete, the demand for constituent materials will increase. To reduce dependence on natural materials, the recycling process of the concrete waste has been encouraged recently. This study applied a heating and grinding method of waste concrete to obtain higher quality recycled coarse aggregate. The addition of vibrations in the mixing process is aimed to enhance the recycled concrete compressive strength. To produce recycled coarse aggregate, the concrete waste was heated to a temperature of 100°C for 24 hours followed by a grinding process using a Los Angeles machine for 600 cycles. Additional vibrations for 30, 60, and 90 were applied in a concrete mixer during the mixing process. Conventional concrete with normal aggregate and no additional vibration during mixing was also provided for comparison. According to the experimental results, the quality of natural coarse aggregate and the recycled one using heating and grinding methods is not much different. Compressive strength of recycled aggregate concrete with vibrations of 30, 60, and 90 seconds increases 21.1%, 22.1%, and 22.6% sequentially correlated to normal concrete. Recycled concrete using heating and grinding methods with the addition of vibration during the mixing process is effective to be used as an alternative to normal coarse aggregate.

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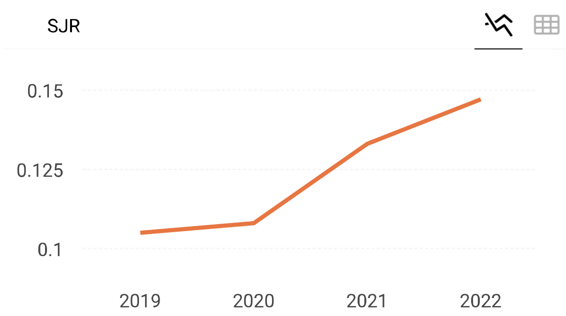
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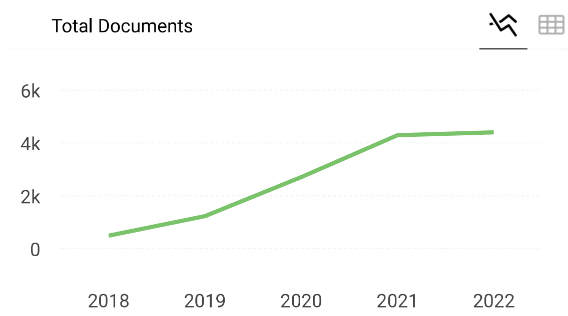
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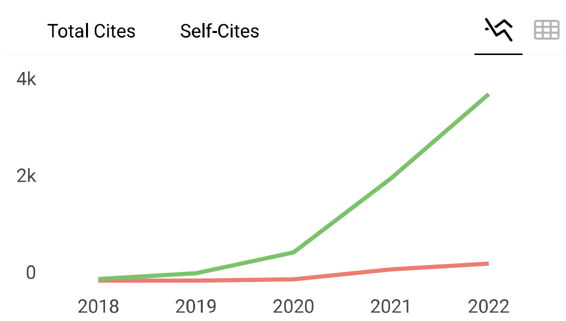
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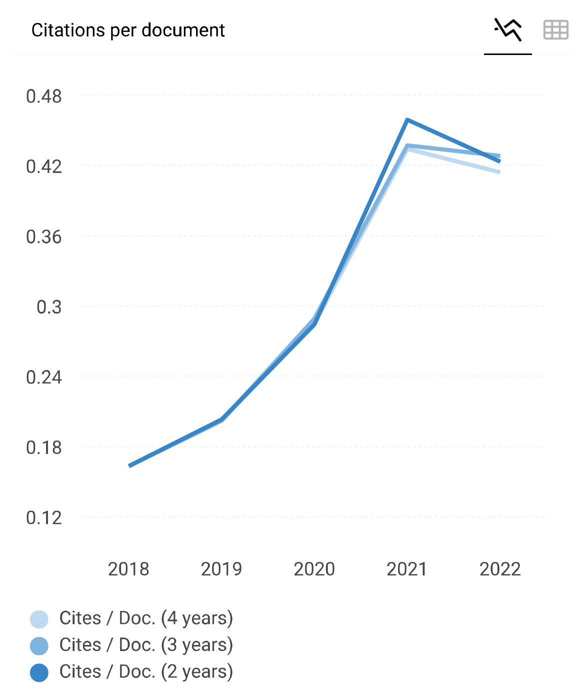
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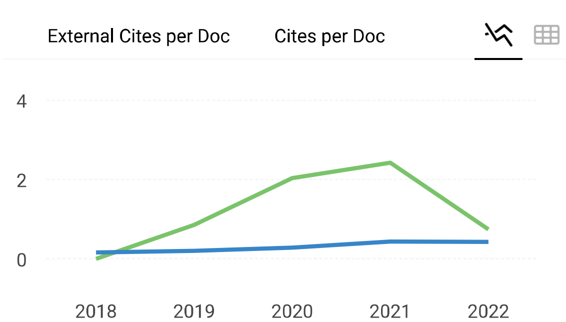
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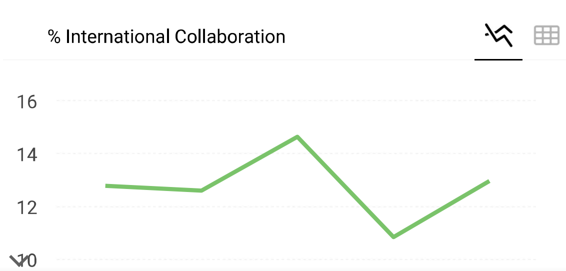
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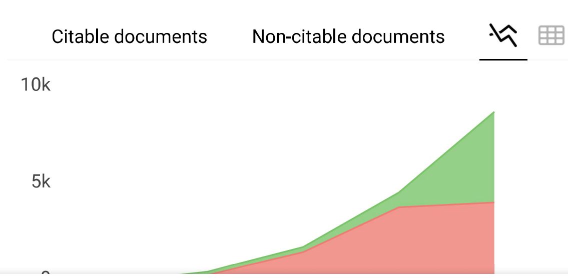
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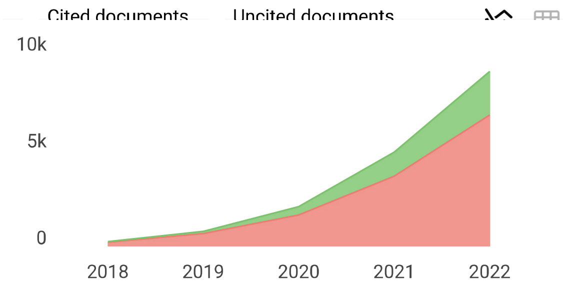

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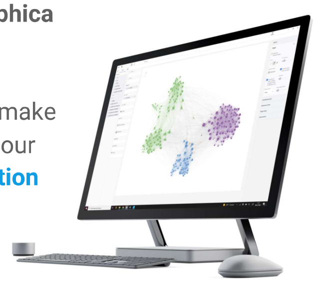

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Abstract. Concrete is a building material that is widely used in the construction industry. With the increasing need for concrete, the demand for constituent materials will increase. To reduce dependence on natural materials, the recycling process of the concrete waste has been encouraged recently. This study applied a heating and grinding method of waste concrete to obtain higher quality recycled coarse aggregate. The addition of vibrations in the mixing process is aimed to enhance the recycled concrete compressive strength. To produce recycled coarse aggregate, the concrete waste was heated to a temperature of 100°C for 24 hours followed by a grinding process using a Los Angeles machine for 600 cycles. Additional vibrations for 30, 60, and 90 were applied in a concrete mixer during the mixing process. Conventional concrete with normal aggregate and no additional vibration during mixing was also provided for comparison. According to the experimental results, the quality of natural coarse aggregate and the recycled one using heating and grinding methods is not much different. Compressive strength of recycled aggregate concrete with vibrations of 30, 60, and 90 seconds increases 21.1%, 22.1%, and 22.6% sequentially correlated to normal concrete. Recycled concrete using heating and grinding methods with the addition of vibration during the mixing process is effective to be used as an alternative to normal coarse aggregate.

1. Introduction

Concrete is the most commonly used construction material. This is because concrete has advantages over other materials. From an economic point of view, the price of concrete is relatively cheap because the ingredient comes from local materials. In addition, concrete has high compressive strength, can be molded into various shapes, and has good resistance to weather and the environment. These advantages make concrete the main choice as a construction material [1–5].

In construction, there are also many concrete wastes resulting from testing and demolition of buildings. A huge amount of construction demolition scrap creates environmental problems for instance the landfill problem due to a large amount of waste generated from the old concrete structures. Another problem that arises is the depletion of natural aggregates because they are used continuously in construction and since the formation of natural aggregates takes a very long time. Thus an alternative is needed to reduce the exploitation of natural aggregates [6–9].

To balance between landfill problem and depletion of natural aggregates, it is in demand to handle recycled aggregate of concrete ruin. The traditional method of recovering recycled aggregate from trash concrete does not reveal any notable quality to be utilized in the assembling of new concrete. The recycled aggregate concrete possesses lower mechanical properties than ordinary concrete. The bonding mortar on coarse aggregates leads to lower quality recycled aggregates [5, 10-11].

The pulsed power method has been used in Japan to reduce the mortar content in aggregates. High stress power is applied to the concrete waste and causes the release of mortar from the aggregate surface. Concrete made from recycled aggregates has a compressive strength that equals concrete made by natural aggregates. However, the pulsed power application is still difficult to be utilized in Indonesia due to huge electricity consumed. Therefore, the other suitable method shall be initiated to produce higher recycled aggregate quality [12–14].

Research conducted by [15-16] concluded that the characteristic of concrete with recycled coarse aggregate produced by the heating-grinding method showed an 8% difference in strength compared to normal aggregate concrete. Thus, recovered coarse aggregate generated by thermal-mechanical methods can be used as an option to normal coarse aggregate. However, efforts to enhance the compressive strength of concrete using this recycled aggregate are continuing ahead. Considering research conducted by [17] stated that the concrete compressive strength can be increased by providing vibration for 1 minute in the middle of the mixing process. Therefore, the vibratory added mixing is adopted in this research to be more effective to promote the characteristic of heating-grinding recycled coarse aggregate concrete. Thus, it is expected to be potential as an alternative material for sustainable concrete shortly.

2. Method and materials

2.1. Recycled aggregate production

The method in the concrete recycling process to extract the recycled aggregate began with collecting the concrete waste and cut it into smaller sizes (20-30 cm). The heating process was conducted by placing the concrete waste in the oven at a heat of 100° C for one day. This process was intended to achieve evaporation of water contained in the mortar pores so that it caused pressure and made it easier to release the mortar from the aggregate during the grinding method.

Grinding was intended for separating coarse aggregate from the existing mortar. This method was carried out with a machine that rotates 600 cycles. The grinding process was assisted by 11 steel balls inside the machine during rotation to rub the old mortar on the aggregate surfaces [15-16].

2.2. Concrete mixture proportion

Two types of concrete were made, the first was the normal concrete prepared from fresh natural coarse aggregate; meanwhile, the second was a concrete production of recycled coarse aggregate. Fine aggregate for both concrete was the same, which was natural sand having a maximum diameter of 4.75 mm. Either natural coarse aggregate or recycled coarse aggregate were having a maximum diameter of 20 mm. The density of fine aggregate and natural aggregate were 2.8 and 2.76 each.

Water cement ratio was held equal among the concrete mixture, which was 0.5, and slump value was designed as 60 mm. The mixture proportion of the concrete contains fresh coarse aggregate and recycled coarse aggregate is presented in Table 1.

Table 1. Concrete mixture proportion.

Concrete type	Weight (kg/m^3)			
	Water	Cement	Fine aggregate	Coarse Aggregate
Normal Concrete	225	450	816	957
Recycled Concrete	225	450	776	911

Based on the Table 1, there was a change in the need for normal coarse aggregate and recycled coarse aggregate. This is due to the change in density. Clearly, the density affects the composition of the concrete mixture where the density of normal coarse aggregate was 2.76, meanwhile, the density of recycled coarse aggregate was 2.57.

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2.3. Concrete mixing and specimens

Generally, the mixing process of normal coarse aggregate concrete were according to standardized mixing process from national code for making concrete specimen [17]. However, there was a modification of mixing stage during making recycled coarse aggregate concrete. The process of giving vibrations was conducted during the concrete mix process with a stick vibrator concrete. This technique of adding vibrations was carried out inside the concrete mixer machine. The vibration was applied at two different points inside the concrete mixer to ensure the vibration effect was uniformly distributed on the fresh concrete. Vibrations were added during the mixing process for 30, 60, and 90 seconds. The variation of the specimen is given in Table 2 meanwhile the method of adding vibration during mixing is illustrated in Figure 1. Cylinder concrete standardized according to the national code for compressive strength measurement was used as specimen. The sizes were 150 mm in diameter and 300 mm in height. The curing time of concrete took place for 28 days to ensure that the hydration process was complete.

Table 2. Variety of vibratory added mixing specimen

Concrete type	Vibratory added mixing (s)
Normal coarse aggregate concrete (NCA)	0
1st Recycled coarse aggregate concrete (RCA-0)	0
2nd Recycled coarse aggregate concrete (RCA-30)	30
3rd Recycled coarse aggregate concrete (RCA-60)	60
4th Recycled coarse aggregate concrete (RCA-90)	90

Figure 1. Method of vibratory added mixing

2.4. Concrete testing

After curing time was completed, the specimens were loaded under compression using compression testing machine until failure. The concrete testing was according to National Standard for compression testing of concrete using cylinder specimen [18]. Prior to the testing, the top surface of the specimens was flattened using sulfuric paste, to achieve a good load transfer from the machine to the concrete. Figure 2 shows the concrete testing.

Figure 2. Concrete testing

3. Result and discussions

3.1. Recycled aggregate physical properties

Table 3 present the characteristics of physics from recycled coarse aggregate compared to the requirement given in the national code for the qualities of coarse aggregate for concrete material making. Meanwhile, Figure 3 illustrates the comparison of physical properties between the normal and recycled coarse aggregate. In general, there is a difference between normal coarse aggregate and recycled coarse aggregate physical properties. The decrease occurred in density and water absorption of recycled coarse aggregate due to adhered old mortar in the surfaces of recycled coarse aggregate. In addition to this reason, the fineness modulus increases. However, the overall physical properties of recycled coarse aggregate still satisfy the aggregate quality standard [19]. In addition, the sieve analysis of the coarse recycled aggregate meets the requirement from the code as shown in Figure 4; even though the result approaches the lower limit the most.

Table 3. Physical properties of coarse recycled aggregate compared the specification from the code

Physical properties	Recycled coarse aggregate	Code specification
SSD density (kg/m^3)	2.57	2.4 – 2.9
Bulk density (kg/m^3)	2.48	2.4 – 2.9
Water absorption (%)	3.32	< 5%
Fineness modulus	6.72	6.0 – 7.1

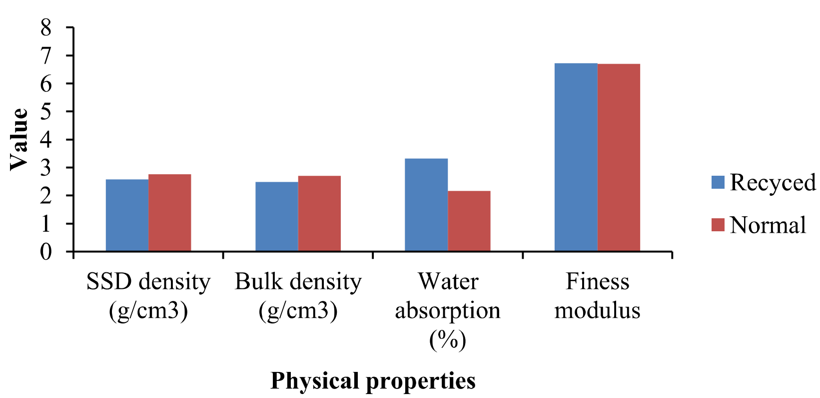

Figure 3. Physical properties of recycled and normal coarse aggregate

Considering the physical properties of conventional recycled aggregate as described in [10], the values obtained in this study show better quality because the surfaces of conventional recycled aggregate are still covered by old mortar entirely. Meanwhile, in this study due to a comprehensive treatment using heating and grinding process; thus, the attached existing mortar can be dismantled effectively. The visualization of recycled coarse aggregate in this study is presented in Figure 5.

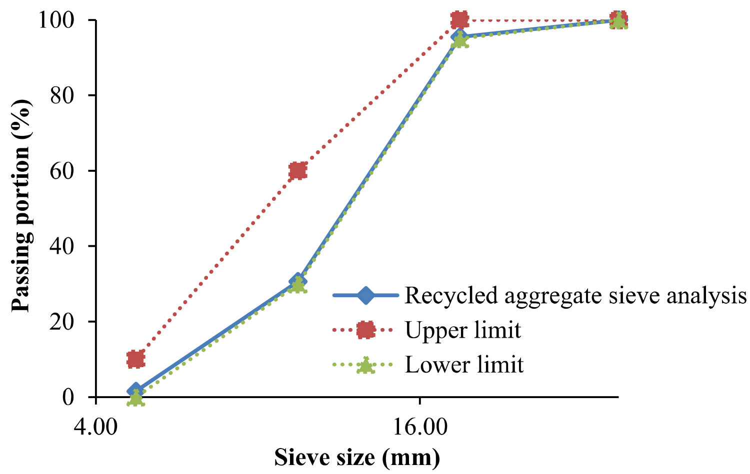

Figure 4. Sieve analysis of recycled coarse aggregate

Figure 5. Visualization of recycled coarse aggregate

3.2. Fresh concrete properties

Concrete with normal coarse aggregate shows the highest slump value. In general, the slump value of concrete with recycled coarse aggregate shows a smaller slump than the slump of normal concrete. This is due to the high water absorption of recycled coarse aggregate, even the SSD aggregate condition was maintained during mixing.

The effect of the vibratory added mixing further exacerbates the decrease in the slump value. Vibration for 90 seconds almost causes the concrete without a slump, which is around 1.17 cm. The slump of recycled concrete with a vibration of 30 and 60 second are in the range of 3-4 cm. The heat released by the vibrator is also assumed to cause a large reduction in the slump value. Concrete slump is presented in Figure 6 and 7.

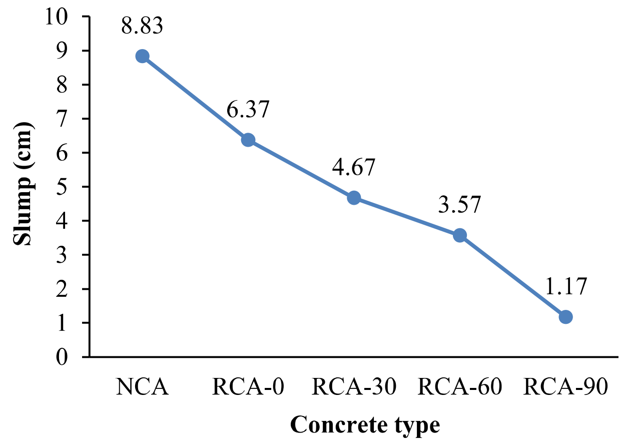

Figure 6. Concrete fresh properties

Figure 7. Slump testing

3.3. Compressive strength

Based on Figure 8, it can be seen that the application of recycled coarse aggregate in the concrete mixture can reduce the strength of concrete by 2.5% seen from the compressive strength of concrete with a normal coarse aggregate of 29.78 MPa and concrete from the recycled coarse aggregate of 29.04 MPa.

The reduction in the compressive strength of the concrete occurs because the mortar is still attached to the recycled coarse aggregate which decreases the quality of the recycled coarse aggregate. However, the use of recycled coarse aggregate with the addition of vibrations of 30, 60, and 90 seconds can improve the strength of concrete by 21.1%, 22.1%, and 22.6% compared to the compressive strength of concrete with a normal coarse aggregate of 29.78 MPa. The compressive strength of recycled coarse aggregate with the addition of vibrations of 30, 60, and 90 seconds are 36.05 MPa, 36.35 MPa, and 36.51 MP respectively. The longest vibration effectively achieves the highest compressive strength. The addition of vibration improves the bonding between recycled aggregate and new cement paste. In addition, the excess pores which exist in the old mortar of recycled aggregate can be filled by the new mortar. As the result, the concrete becomes denser and eventually, the compressive strength increases. More than one stage mixing has been reported by [5]. This result is in line with the result of this study that adding some processes during mixing enables to improve the performance of the recycled concrete.

Even the recycled aggregate concrete compressive strength is still lower than that of normal aggregate concrete; the vibratory added mixing can improve the recycled concrete effectively by around 20%. Among the addition of vibrations of 30, 60, and 90 seconds, each does not contribute many different results significantly. The compressive strength is only different 0.5 - 1.3% among the existing vibratory methods. Contrary to the lowest workability level based on the slump test, the 90 seconds vibratory results the largest compressive strength. An addition of either mixing water or superplasticizer is recommended to maintain the good workability level.

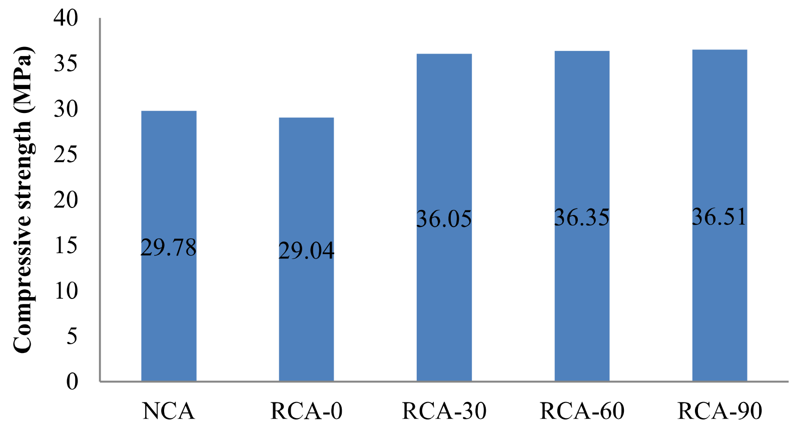

Figure 8. Concrete compressive strength

4. Conclusion

The physical properties of recycled coarse aggregate meet the aggregate quality standard based on the national code. The slump value of concrete with recycled coarse aggregate shows a lower slump than the slump of normal concrete. The decrease is seen significantly due to vibratory added mixing concrete. The heat released by the vibrator is assumed to cause a large reduction in the slump value. The use of recycled coarse aggregate in the concrete mixture reduces the strength of concrete by 2.5% compared to normal coarse aggregate concrete. However, the application of vibratory during mixing enables to improve the recycled concrete compressive strength effectively by around 20% compared to the compressive strength of normal concrete. Furthermore, an addition of either mixing water or superplasticizer is recommended to maintain the good workability level of recycled concrete made with vibratory added mixing.

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