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Effects of crushed stone waste as fine aggregate on mortar and concrete properties

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Abstract. In this study, effects of crushed stone waste from Katunun's quarry as fine aggregate on mortar and concrete properties will be examined. Samples with varying crushed stone waste replacement ratio, ranging between 0% until 100%, will be analysed at 3, 7 and 28 days curing time. Mortar sample is using 0.5 w/c ratio, while concrete sample is using 0.45 w/c ratio. The mixture of mortar sample is based on SNI 03-6825-2002, whilst concrete sample is based on SNI 03-2834-2000. The examination of concrete samples workability was conducted based on the slump test according to SNI 1972:2008. Moreover, the compressive strength test of mortar sample is based on SNI 03-6825-2002. In addition, the compressive strength test of concrete sample is based on SNI 1974:2011. Regarding compressive strength of mortar samples, the average compressive strength results of mortar with crushed stone waste rose significantly in line with the increase in replacement ratio. As for the workability of fresh concrete, sample using natural river sand had better workability compared to sample using crushed stone waste. However, the workability of concrete with crushed stone waste is still meet the slump value specified in the job mix formula. In addition, it has been found out that the combination of 75% crushed stone waste with 25% river sand will give the highest compressive strength compared to others combinations. Based on these findings, the utilization of crushed stone waste from Katunun's quarry in mortar and concrete mixture can be proposed.

1. Introduction

As a developing country, Indonesia continues to develop infrastructure and build buildings not only by the government but also by private companies. Therefore, the need for construction materials continues to increase. This has caused many new material quarries appeared in all regions of Indonesia.

As one of the regions in Indonesia that has abundant natural resources, South Borneo not only has coal and gem mines but also have a lot of material quarries spread out through the region. One of the examples is quarry located in Katunun, Pelaihari city. Many construction materials used in South and Central Kalimantan, especially as coarse aggregates, originated from this location. The aggregate from this location is preferred due to its abrasion value of around 15-25%, which is very good as a course aggregate. The results of concrete research using Katunun stone have also proven this fact, not only in research related to normal concrete but also in research related to concrete with mineral admixture [1], [2].

However, the increase in coarse aggregate production has caused problems for people around the stone-crusher plant. For instance, one of stone-crusher plant located in Pelaihari city in South Borneo has been producing 5 - 7 tons crushed stone waste every day. This means that the waste will reach up to 210 tons per month or 2520 tons per years. The accumulation of waste in the plant results in waste pollution that endangers the surrounding community, especially as one of the causes of various respiratory diseases in the surrounding area. Only little utilization of this waste has been wrought. The



most common utilization is as a part of bulk filling materials in road construction. This utilization still does not significantly reduce waste at the plant yet.

Recently, there have been several studies carried out relating to the use of this waste, especially as a replacement of fine aggregates in concrete [3]–[10]. It is proved that the crushed stone waste can be used economically as replacement to the natural river sand and ecologically help to reduce the excessive mining of river sand [3]. In terms of mechanical properties of concrete with crushed stone waste, researchers found that the replacement of fine aggregate with crushed stone waste can improve compressive strength, flexural strength and tensile strength of concrete [5], [7], [11]–[16]. Based on these findings, it is possible to utilize the crushed stone waste from Katunun's quarry in Pelaihari, South Borneo, as a replacement for fine aggregate. Nonetheless, validation through research still has to be conducted.

In this study, effects of crushed stone waste from Katunun's quarry as fine aggregate on mortar and concrete properties will be examined. Samples with varying crushed stone waste replacement ratio, ranging between 0% until 100%, will be analysed at 3, 7 and 28 days curing time. From this study, it is expected to prove the utilization of crushed stone waste from Katunun's quarry as fine aggregate in mortar and concrete mixture.

2. Materials and methods

2.1. Materials

Portland pozzolanic cement (PPC), from G Co, Ltd., was used. In order to investigate the effects of crushed stone waste from Katunun's quarry as fine aggregate on mortar and concrete properties, crushed stone waste from J. A. B. ready mix concrete plant located in South Borneo was used. The fine aggregate was obtained from natural river sand in South Borneo. While the coarse aggregate was taken from Katunun quarry in South Borneo.

2.2. Methods

The properties of mortar and concrete with crushed stone waste from Katunun's quarry were investigated through 30 samples of mortar and 45 samples of concrete. The variations are ordinary concrete (0%), 25%, 50%, 75% and 100% replacement ratio of river sand with crushed stone waste. Mortar sample is using 0.5 w/c ratio, while concrete sample is using 0.45 w/c ratio. As for the curing time, mortar sample is set at 28 days curing time and concrete sample is set at 3, 7 and 28 days curing time. The size of mortar cube sample is 50 x 50 x 50 mm and the size of concrete cylinder sample is 150 x 300 mm. Furthermore, the mixture of mortar sample is based on SNI 03-6825-2002 [17], whilst concrete sample is based on SNI 03-2834-2000 [18]. The examination of concrete samples workability was conducted based on the slump test according to SNI 1972:2008 [19]. Moreover, the compressive strength test of mortar sample is based on SNI 03-6825-2002 [17]. In addition, the compressive strength test of concrete sample is based on SNI 1974:2011 [20]. The complete mixture proportions of mortar samples and concrete samples are shown in Table 1 and Table 2.

Table 1. The mixture proportions of mortar samples.

No	Sample type	Water to cement ratio	Crushed stone waste ratio	Material requirements for every 6 samples			
				Cement (gr)	Water (ml)	Fine Aggregate (gr)	Crushed stone waste (gr)
1	SM1	0.5	0%	500	250	1375	0
2	SM2	0.5	25%	500	250	1031.25	343.75
3	SM3	0.5	50%	500	250	687.5	687.5
4	SM4	0.5	75%	500	250	343.75	1031.25
5	SM5	0.5	100%	500	250	0	1375

Table 2. The mixture proportions of concrete samples.

No	Sample type	Water to cement ratio	Crushed stone waste ratio	Material requirements for every 5 samples				
				Cement (kg)	Water (l)	Fine Aggregate (kg)	Crushed stone waste (kg)	Coarse Aggregate (kg)
1	SC1	0.45	0%	14.44	6.50	18,15	0	35,17
2	SC2	0.45	75%	14.44	6.50	4,54	13,61	35,17
3	SC3	0.45	100%	14.44	6.50	0	18,15	35,17

3. Results and discussion

3.1. Compressive strength of mortar samples

The compressive strength tests for all mortar samples were conducted according to SNI 03-6825-2002 [17]. The compressive strength tests were carried out at 28 days curing time. Complete average compressive strength test results could be seen in Figure 1.

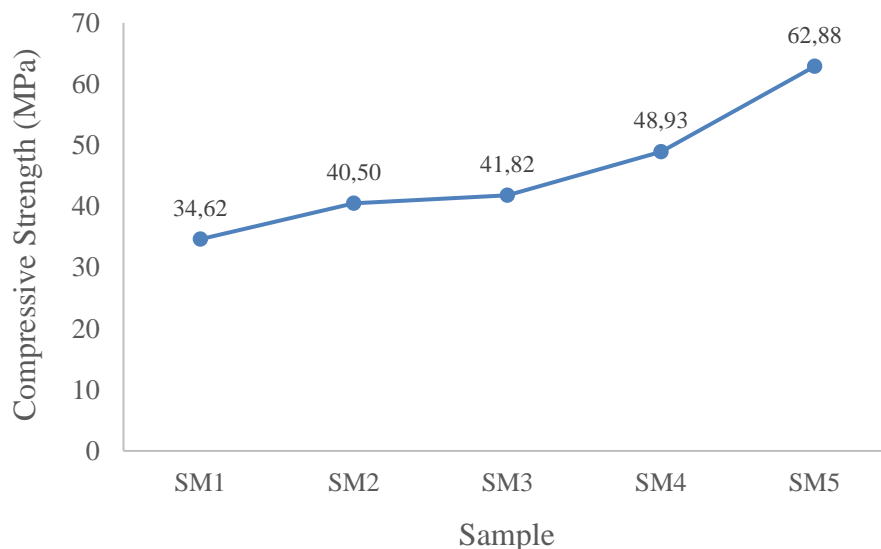


Figure 1. Average compressive strength test results for mortar samples at 28 days curing time.

Based on the figure above, it can be seen that the average compressive strength results of mortar with crushed stone waste rose significantly in line with the increase in replacement ratio. This might be due to differences in shape, surface roughness and water absorption between natural river sand and crushed stone waste [12]. In addition, the water absorption test also reveals bigger water absorption of crushed stone waste compared to river sand.

It is known that the angular shape of aggregate will yield higher strength due to its better interlocking effect and higher bond characteristic between aggregate and cement paste [21]. From this results, for mortar applications in construction, it is better to use crushed stone waste then river sand. Furthermore, in terms of ecological, the use of crushed stone waste will also help to sustain the natural resources.

3.2. Workability

Workability analysis was conducted based on the slump test according to SNI 1972:2008 [19]. Since the compressive strength of mortar shows the preeminence of higher crushed stone waste replacement ratio, concrete samples are only made with 0% (normal concrete), 75% and 100% crushed stone waste replacement ratio. From the concrete's job mix formula, the slump target is 8 ± 2 cm. The results of concrete slump test could be seen in Table 3.

Table 3. Slump test results.

NO	Sample type	Crushed stone waste ratio (%)	Slump test results (cm)
1	SC1	0	9,5
2	SC2	75	7.5
3	SC3	100	7

The results show that SC1 sample (using natural river sand) had better workability compared to SC2 and SC3 sample (using crushed stone waste). This result could confirm the effect of angularity difference between crushed rock and natural sand as mentioned above. More water will be required for angular aggregate with rough texture to have a better or at least equal workability compared to rounded aggregate [21]. As the water absorption of crushed stone waste is higher, this also contributes to lower workability compared to concrete with natural river sand. Nonetheless, the slump test results showed that all samples meet the slump value specified in the job mix formula. With a slump value around 8, it can facilitate the casting process in construction work due to the concrete mixture is not too thick.

3.3. Compressive strength of concrete samples

The compressive strength tests were conducted according to SNI 1974:2011 [20]. All samples were tested at 3, 7 and 28 days curing time. Complete test results could be seen in Figure 2 until Figure 4 for samples with 3, 7 and 28 days curing time, respectively.

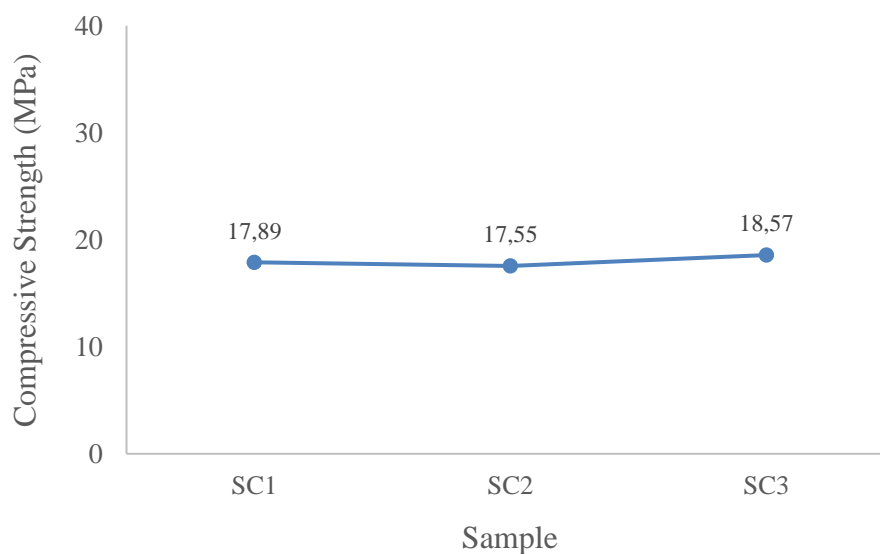


Figure 2. Average compressive strength test results for concrete samples at 3 days curing time.

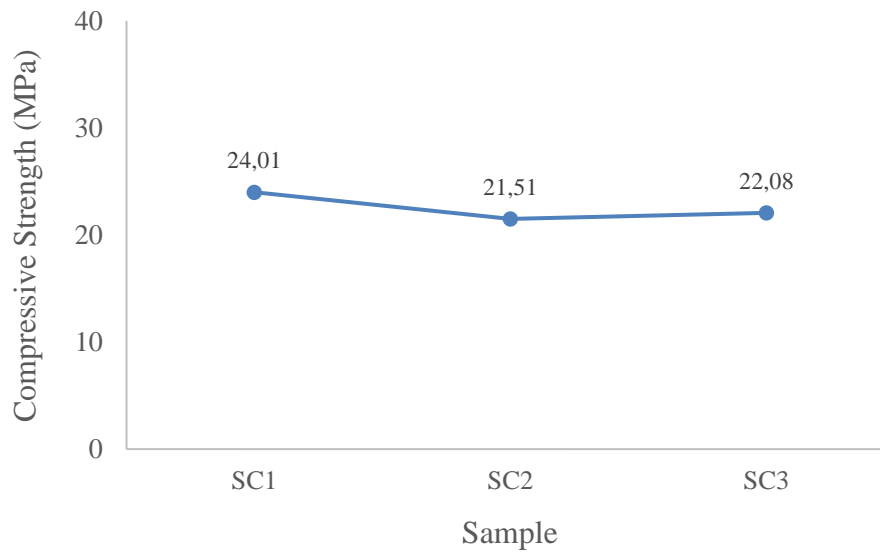


Figure 3. Average compressive strength test results for concrete samples at 7 days curing time.

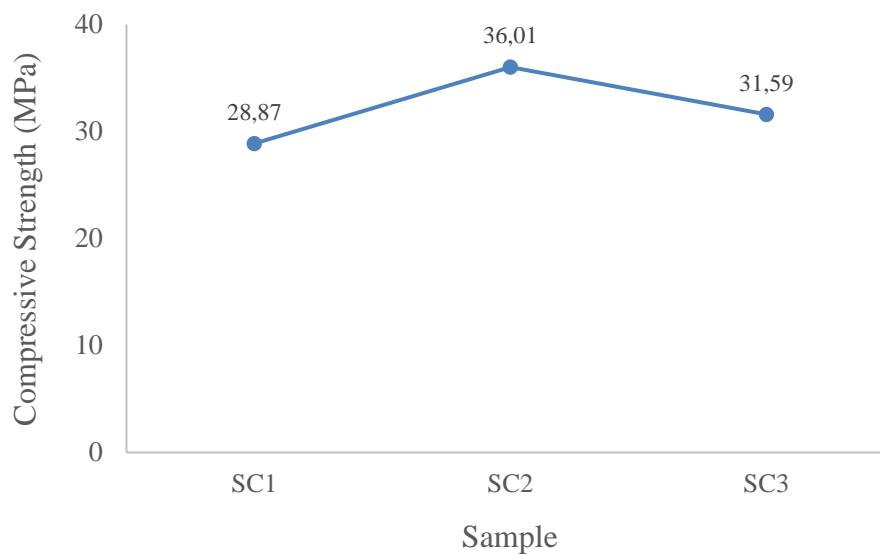


Figure 4. Average compressive strength test results for concrete samples at 28 days curing time.

The pattern of average compressive strength test results for 3, 7 and 28 days curing time are slightly different. Samples with 3 days curing time show that the compressive strength of all samples is quite the same around 18 MPa. On the contrary, 7 days curing time samples indicate a significant increase of strength for SC1 sample (normal concrete) compared to samples with crushed stone waste. However, in Figure 4, samples with crushed stone waste show superiority in terms of strength compared to normal concrete, especially for SC2 sample.

The delay in strength development of concrete with crushed stone waste was also noted by previous research [7], [15]. The compressive strength of concrete with crushed stone waste seemingly delayed at earlier ages. But, after 7 days, there is a significant increase in strength compared to normal concrete. Once again, the differences in shape, surface roughness and water absorption might be the reason behind this phenomenon [12], [21]. Due to crushed stone waste has greater surface area compared to rounded river sand, it takes time for cement paste to cover/coats the crushed stone waste. Thus, it appears that the increase in the strength of concrete with crushed stone waste is delayed. However,

greater surface area will result in higher bond strength [21]. That is why at 28 days curing time SC2 and SC3 samples possess superior strength compared to SC1 sample.

Another interesting fact that could be found is the significant difference in terms of strength between SC2 and SC3 samples. This finding is in accordance with previous studies [3], [4], [6], [9], [14]. One explanation is that the sharp, angular aggregates with rough surfaces should have a slightly finer grading in order to compensate for the high friction between the particles [22]. In the presence of river sand, that has a finer gradation, it will be able to fill the void between the aggregates so that the concrete becomes denser. Furthermore, aggregate with moderate or low strength (i.e. river sand) can be valuable in preserving the integrity of concrete due to this type of aggregate would reduce distress in concrete while on the contrary, cracking of the surrounding cement paste could be found in concrete with a strong and rigid aggregate [22].

4. Conclusions

The purpose of this research was to analyze effects of crushed stone waste from Katunun's quarry as fine aggregate on mortar and concrete properties. In terms of compressive strength of mortar samples, the average compressive strength results of mortar with crushed stone waste rose significantly in line with the increase in replacement ratio. Hence, for mortar applications in construction, it is better to use crushed stone waste than river sand.

However, as for the workability of fresh concrete, sample using natural river sand had better workability compared to sample using crushed stone waste. In general speaking, the workability of concrete with crushed stone waste is still meet the slump value specified in the job mix formula. With a slump value around 8, it can facilitate the casting process in construction work due to the concrete mixture is not too thick.

As for the compressive strength of concrete samples, it has been found out that the combination of 75% crushed stone waste with 25% river sand will give the highest compressive strength compared to others combinations. The difference in strength is quite significant from the three combinations. Based on these findings, the utilization of crushed stone waste from Katunun's quarry in mortar and concrete mixture can be proposed. Especially for the replacement of 75% crushed stone waste, there is a confidence that this fine aggregate could be used to produce a high strength concrete.

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