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The impact of different of coarse aggregate size on the strength and performance of concrete using locally available materials

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Abstract

This study examined coarse aggregates of various sizes and their effect on the compressive strength of concrete. This study was taken by the consideration of different locally available materials in Madura Island. Those materials were damaged to varying degrees due to inadequate selection and handling of the coarse aggregate, which makes up the majority of the concrete material. In Madura, most of the construction using those type of aggregates which only reached the compressive strength capacity less than 20 MPa. In this study, two concrete samples were prepared, CS1 and CS2 using two combination of coarse aggregate sizes, 5 mm – 10 mm and 10 mm – 20 mm with ordinary Portland cement and natural river sand as the fine aggregate and polymer admixture to keep workability. Specimen control of each condition were also prepared. The water-cement ratio of 1: 2: 4 and 0.55 was maintained throughout the study. Targeted concrete slump flow is 60 ± 5 mm. After 28 days of curing, the compressive strength test of a 300 x 300 mm concrete cylinder showed the highest compressive strength of 33.28 MPa for CS1, followed by 36.10 MPa for CS2. These different compressive strength properties are the result of coarse aggregate resizing, thus determining the effect of coarse aggregate size on concrete. Furthermore, the size of coarse aggregate does not affect significantly on the performance of the concrete.

Keywords: Concrete strength, coarse aggregate sizes, concrete mixtures, characteristic compressive strength, local material

Introduction

Concrete is made from a combination of coarse aggregates (gravel), fine aggregates (sand), cement, and water that is allowed to cure over time. As a result, the compressive strength of concrete is primarily determined by a number of factors, including the size and shape of coarse aggregates (Woode and Ballow 2015).

Aggregate particles are generally accepted to be present in various sizes and are described by separating them with a square sieve for technical identification purposes (Habert 2013; Rodríguez-Robles, Van Den Heede, and De Belie 2018). Due to the large size of concrete aggregate, it falls into two categories: coarse aggregate and fine aggregate. Fine aggregate is particles smaller than 5 mm and coarse aggregate is particles larger than 5 mm. The effects of fine aggregates on the strength of concrete are almost entirely based on their shape, texture, and particle effects on the mixed water required for workability (Abdun-Nur et al. 1987; Collins and Kuchma 2000; Dhir et al. n.d.; George 2011; Ranade 2014; Standard 2002; Tchetgnia Ngassam, Arito, and Beushausen 2018).

Coarse aggregate refers to aggregate with particles larger than 5 mm in size. Aggregate should be composed of particles that are strong enough and resistant to exposure and should contain no more than 5% by weight slate, silt, and structurally weak particles (Quayson and Mustapha 2019). The shape of the particles affects the behavior of the water-cement ratio. Aggregate with rough edges in concrete has a high void content, which can reduce strength and weaken concrete. The most suitable aggregate is well-sloping, angular particles whose surface structure is not too smooth. Freshwater river aggregates are well classified and have been found to be more suitable, but sea and estuary aggregates are moist due to deliquescent if salt (magnesium and sodium chloride) is not removed. It is inappropriate because it attracts (Guades 2019).

The effect of coarse aggregates on cement-based concrete has been extensively researched. Salau and Busari (Salau and Busari 2015), for example, characterised the effect of aggregate size on the strength of a laterised concrete. Workability, density, and compressive strength at constant water-cement ratios were found to increase with coarse aggregate particle size and curing age. Vu, Daudeville, and Malecot (Vu, Daudeville, and Malecot 2011) determined the effect of coarse aggregate size and volume of cement paste on the behavior of concrete under strong triaxial stress. The results suggested that when the coarse aggregate size is increased, the concrete strength increases marginally. At high confinement, coarse aggregate size has a minor effect on the deviatoric behavior of concrete but a large effect on the strain limit state of concrete. They reported that as coarse aggregate size increases, the mean stress level corresponding to the concrete strain limit condition decreases.

The purpose of this study is to investigate the effect of coarse grain variation on concrete strength development and to determine the coarse grain that gives the highest compressive strength. This investigation comes from the condition of Madura Island which is famous as the mining production of aggregate both of coarse aggregate and fines aggregate. In fact, the quality of those aggregate is still under the required standard, this is approved by several investigation by previous researcher (Nasser 2018; Susanti et al. 2021). In addition, according to development of economic growth in East Java, the construction of the infrastructure in Madura is now rapidly improved and needed the implementation of the high strength concrete as the support of structural element as column, beam, pillar, etc (Li 2009; Rodríguez-Robles et al. 2018; Thomas, Fellows, and Sorensen 2018)

Investigation Review

Coarse aggregate accounts for 50-60% of the concrete volume, depending on the mixing ratio, and is therefore considered a determinant of concrete strength. Studies have shown that changing the size, grade and type of coarse aggregate can change the strength and fracture properties of concrete (Kalra and Mehmood 2018). Another investigated study also evaluates the effects of various types of coarse aggregate on the compressive strength of concrete and found that high-strength coarse aggregate has high compressive strength, whereas normal-strength concrete has coarseness. We observed that the strength of the aggregate was small (Pertiwi and Choiriyah 2018; Quayson and Mustapha 2019)

The study of the effect of coarse aggregate size on several concrete properties such as fracture energy and compressive strength was controversial among researchers. Li et all (2021) reported that the larger the size of the aggregate, the higher the fracture toughness. However, for high-strength concrete that breaks when the coarse aggregate breaks, the size of the concrete does not affect the fracture properties of the concrete (Li et al. 2021). The distribution of improved materials using locally available material also conducted by various researcher in Surabaya, in order to have a support behaviour of local used materials. Those materials are used to be designed a new novel engineered cementitious composite (without coarse aggregate) compared to a normal concrete (Bastian et al. 2020; Komara et al. 2020; Komara, Tambusay, Sutrisno, and Suprobo 2019; Komara, Tambusay, Sutrisno, Suprobo, et al. 2019; Mooy et al. 2020; Oktaviani et al. 2020). Susanti et al also investigated the typical Madura's materials implemented by supplementary cementitious material fly ash (Susanti et al. 2021).

Several studies have been conducted on the effects of various aggregate sizes on the strength of structural concrete. Guades (2017) investigated the effect of aggregate sizes under geopolymer concrete, the result also investigate the type of the mode failure (Guades 2019; Mallikarjuna Reddy and Manikanta Sai Swaroop 2020). This term of behaviour related to the condition of construction of the structure since a concrete material imply the main support of fracture mechanism according to various study (Komara et al. 2021; Nareswarananindya et al. 2021; Pertiwi, Komara, and Fristian 2021)

Kalra and Mehmood (2018) and reddy and Swaroop (2020) found that increasing aggregate size reduces the compressive strength of concrete under the condition of full recycled of coarse aggregate (Kalra and Mehmood 2018; Mallikarjuna Reddy and Manikanta Sai Swaroop 2020). It was shown that the compressive strength increases with larger aggregate size (Atiş 2003; Basha, Pavithra, and Reddy 2014; Quayson and Mustapha 2019). Another study concluded that above 69 MPa, smaller coarse aggregates produce higher strength at a given water-cement ratio (Alexander, Dehn, and Moyo 2008; Mehta and Monteiro 2001). Ajamu and Ige (2015) concluded that the coarse grain size is directly proportional to the slump of fresh concrete with a constant water content, and the compressive strength of concrete increases with increasing coarse grain size (Alexander, Dehn, and Moyo 2015; Research Board et al. n.d.; Standard 2002; Susanti et al. 2021).

(Pertiwi and Choiriyah 2018) also conducted experimental investigation using Madura coarse aggregates. The water cement ratio of 0.4 was completely mix to the design within 10 to 20 mm coarse aggregate under the compressive strength capacity 25 MPa. The result shown that the characteristic compressive strength was lower than the minimum designed, 14.5 MPa. The correction stated that most of materials specification was not filled the standard due to the characterization of materials type. (Kenai 2018) also investigated experimental study using Madura coarse aggregate within the concentration of improvement by the influence of various number admixtures. The characteristic of compressive strength is increased but the slump value is not achieved. Due to the workability concerning to the easiest mobility of the concrete, this study needs to be revaluated which investigated the maximum portion of the admixture.

According to (Meddah, Zitouni, and Belâabes 2010), compressive strength increases with aggregate type. (Mallikarjuna Reddy and Manikanta Sai Swaroop 2020) state that the type of coarse aggregate used reduces the compressive strength of concrete. Ruiz (2006) discovered, on the other hand, that the compressive strength of concrete increases as the coarse aggregate content increases until a critical volume is reached. Per the (Tchetgnia Ngassam et al. 2018), the compressive strength of concrete is directly affected by the water-to-cement ratio, degree of compaction, cement-to-aggregate ratio, bond between mortar and aggregate, grading, shape, strength, and size of the aggregate. The methods used in this study are discussed in the preceding section. It goes on to describe the instruments and materials used during the experiment, including how the experiments were conducted.

While the effect of coarse aggregate size on the compressive strength and other parameters of cement-based concrete has been extensively investigated, there is no published evidence of how coarse aggregate size affects the concrete performance compared to distribution of fine and coarse aggregate implied to concrete composition. Considering this study gap, this study aims to determine the effect of coarse aggregate size variation on the compressive strength properties of concrete. To achieve this, concrete samples with the same mixing ratio but with different sizes of coarse aggregate are prepared and tested. This study provides a better understanding of the role of coarse aggregate and the effect of their size on the development of compressive strength in concrete.

Materials and Methods

Locally Available Material

The materials used in this study were coarse aggregate sieved to two different sizes category i.e., size 10/20 mm and 5-10 mm, fine aggregate (river sand), ordinary Portland cement, clean water. All the describe materials used in this study were obtained from Madura's Island in the region of East Java, Indonesia. The laboratory instruments used for the work include a universal testing machine with a capacity 3000kN, 300 mm x 300 mm cylinder molds, weighing shape and scale, slump cone apparatus, base plate, compacting apparatus, manual sieve set, tamping rod and concrete mixer capacity 1 m3. In addition, the coarse aggregate comes from the same quarry to ensure the consistent properties and all materials clearly investigated to understanding the behaviour.

Investigation method

All required materials were batched by weight including the two coarse aggregates according to the Indonesian specifications SNI 03-2834-2000 (Badan Standardisasi Nasional 2002). The mixing ratio of concrete cylinder then was corrected by volume, in a proportion of cement, fine aggregate and coarse aggregate of 1: 2: 4 for concrete grade C35. The water-cement ratio was maintained at 0.55. The material was mixed in a concrete mixer then cast in cylinder molds before testing. The total specimen for two-variety is 18 specimen and placed by the duration of curing. During the mixing, a slump test was performed to ensure good consistency of the mixture according to SNI 03-1972-2018. Each coarse particle size was represented by a set of concrete cylinders measuring 300 mm x 300 mm in the form of CS1 (size 5/10) and CS2 (size 10/20). The cylinder was made from a fresh concrete mix according to SNI 03-2834-2000 and was demolded after 24 hours. To ensure the specimen was still in a good condition then it was cured for 7, 14, and 28 days using the normal water on the curing camber. Concrete samples were tested under compressive strength after a specific curing day, 7, 14 and 28 days. The testing specimen was conducted according to standard (ASTM 2014).

The compression test was performed on a compression tester according to SNI 1974-2011. The compression strength equation is given by Equation 1. The strength development rate of the concrete sample was calculated as shown in Equations 2-4.

$$Compressive\ Strength = \frac{F}{A} \tag{1}$$

Where: F is a crushing load (kN) and A is the area of the surface of concrete specimen (mm2)

when the investigation is evaluated by the curing criteria according to SNI 03-2834-2000 for 7, 14 and 28 days the evaluation is classified as Equation 2-4.

$$Dailiy\ strength\ (0-7) = \frac{Strength\ at\ 7\ days\ curing}{Number\ of\ days\ between\ 0\ and\ 7} \tag{2}$$

$$Dailiy\ strength\ (7-14) = \frac{Strength\ at\ 14\ days\ -\ strength\ at\ 7\ days}{Number\ of\ days\ between\ 7\ and\ 14} \tag{3}$$

$$Dailiy\ strength\ (14-28) = \frac{Strength\ at\ 28\ days\ -\ strength\ at\ 14\ days}{Number\ of\ days\ between\ 14\ and\ 28} \tag{4}$$

Results and Discussion

Classification of used materials

The mixing ratio of concrete cylinder was maintained at 1: 2: 4 with a constant water-cement ratio of 0.55. The slump test was conducted to ensure a certain amount of water in the concrete mixture. The effect of coarse particle size variation at a constant water-cement ratio was also determined by this test. The mix design composition can be seen on Table 1 while the total summary of needed material for one m3 can be seen on Table 2. It shows the mixing ratio and the slump test results obtained from the experimental investigation. Figure 1 illustrates the slump test for concrete of two various sizes using Madura coarse aggregate CS1 and CS2. These results show that 5-10 mm aggregate size give the highest slump values compared to the coarse aggregate of 10-20 mm.

The material investigation is necessary to be conducted in this study to control each material behaviour. All needed investigation is presented in Table 2, while the mixture composition of C35 for both CS1 and CS2 presented in Table 3.

Table 1. Mix design of concrete C35 according to SNI 03-2834-2000

No.	Item description job	Related evaluation	Result value	
1	Compressive strength characteristics	Determined	35	MPa (curing time 28 days)
	Test specimen cube / cylinder with the maximum limitation of corrected specimen not over 5%			
2	Deviation standard	Based on the number of specimens	6	MPa
3	Added value (margin)	1,64 x (2)	9,84	MPa
4	Average compressive strength characteristic	(1) + (3)	44,84	MPa
5	Cement type	Determined	Type I	
6	Specific gravity of coarse aggregate	2,58	Madura's Split coarse aggregate	
	Specific gravity of fine aggregate	2,67	River sand	
7	A free water cement ratio	Appendix T.2 and G1	0,42	The small value
8	A maximum water cement ratio	Determined	0,60	
9	Slump	Determined	0 - 10	mm
10	Maximum size of coarse aggregate	Determined	5-10/ 10-20	mm
11	Water content	Appendix T.3	170	kg/m3
12	Total Cement content	(11) / (8)	404,76	kg/m3
13	Cement content	Determined	404,76	kg/m3
14	Maximum cement content	Determined	404,76	kg/cm3
15	Adjustment water cement ratio			
16	The grading of the fine aggregate grains	Appendix G.3 to G.6	Zone 2	
17	% of fine aggregate	appendix G.13 to G.15	28	%
18	Relative Combined specific gravity	Determined	2,61	kg/m3
19	Concrete filler	appendix G.16	2400	kg/m3
20	Combined aggregate rate	(19) - (12 + 11)	1825,24	kg/m3
21	Fine aggregate content	(17) x (20)	511,07	kg/m3
		(20) – (21)	1314,17	kg/m3
22	Coarse aggregate content	Coarse aggregate 10 – 20 : 58%	1057,91	kg/m3
		Coarse aggregate 5 – 10 : 14%	256,26	kg/m3

The mixture proportion for both mixture is typically the same, the only different is based on the coarse aggregate, CS1 and CS2, respectively. To maximize the composition 1% polymer superplasticizer is added into the mixture. All the material that is mixed into C35 fill the required standard according to SNI and ASTM. To evaluate the mixture proportion, material investigation is adopted for both coarse aggregate types. All investigation follows all specification design then calculate for the mixture composition in excel spread sheets as the given illustration in Table 3.

Table 2. Material Investigation for both coarse aggregate type

Materials investigation	**CS1**	**CS1**	**standard**	**Code**
Concrete moisture (%)	2,0	1,95	1 - 5	ASTM C 556 – 89
Specific gravity (gr/cm3)	2,58	2,97	1,60 – 3,30	ASTM C128 – 93
Water infiltration (%)	3,72	1,06	< 4	ASTM C 128 – 93
Volume weight – freed (kg/dm³)	1,37	1,32	0,4 - 1,9	ASTM C 29

Volume weight -condense (kg/dm³)	1,37	1,54	0,4 - 1,9	ASTM C 29
Mud content (%)	2,35 %	1,75	< 5	ASTM C 117 – 95
Sieve analysis	5,99	7,97	6,5 < Fm <8,0	ASTM C 33
Gradation Los Angeles (%)	2,0	31,54	< 40	SNI 2417 : 2008

Table 3. Mixture composition of C35

Material	**CS1**	**CS2**
Cement (kg/m3)	404.76	404.76
Water (lt)	165	165
Fine Aggregate (kg)	523.79	523.79
Coarse Aggregate 10-20 (kg)	-	1305.44
Coarse Aggregate 5-10 (kg)	1305.44	-
Polymer Superplasticizer (kg)	4.1	4.1

Strength and concrete performance

Firstly first, for area computation, the important dimensions i.e., the diameter of the specimen were obtained prior to testing. All cylinder specimens were tested for compressive strength utilizing an ASTM C873 M-certified compressive testing equipment with a capacity of 200 kN. Snap photos of the specimen under test were also taken to document the manner of failure. The compressive testing equipment and test setup utilized in the investigation are shown in Figure 1 followed by the illustration of the most specimen failure. The failure patterns observed for all concrete when subjected to compressive force nearly typical close to cone failure to split. Shear failure to columnar are not informed in this investigation. A few of the samples originally failed due to concrete crushing in the compression face. On the other hand, as illustrated in Figure 1, cracking throughout the length of the specimen was detected as a result of splitting owing to the formation of tensile stresses.

(a) Mixing the specimen (b) Compressive test set-up (c) Cone and split failure mode

Figure 1. Compressive test set up within the mode of the tested failure

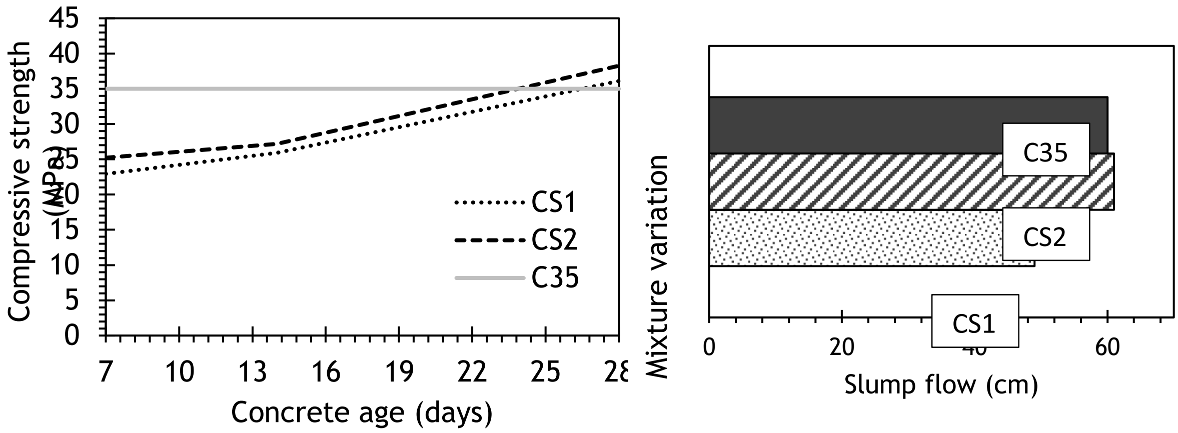

Figure 2. Compressive strength vs. slump flow under variety of concrete specimen

Figures 2 illustrate a graph depicting the influence of increasing of slump flow on compressive strength at various curing durations. The values used in charting the data point shows that the CS1 is a bit lower than the CS2 since the implication of averaging the particle size range's bottom and upper boundaries (mean size). The compressive strength of both coarse aggregates typically rises as the mean size of the aggregates increases, as seen by the Figure 2. However, this is only true up to a certain point under the condition of slump flow, beyond which the compressive strength of CS1 concrete begins to decline as the slump flow decrease. There are two major explanations for this occurrence. For starters, larger aggregate sizes result in a broader aggregate–paste interface. This inter-facial zone develops a weak spot, and cracking begins there (Garrison, 2007).

Larger cracks may occur at the interface, and they can readily interact with paste cracks as well as other interfacial cracks, lowering compressive strength. Second, when water becomes trapped on the underside of the larger aggregate, internal bleeding ensues. When the stored water evaporates, this results in the production of voids, reducing the concrete's strength. In term of the compressive strength for all compared specimens, through the precedence investigation CS2 offer slightly a better performance than the CS1, it was studied that the failure mode is typically similar one and another according to the specification of concrete C35.

Conclusion

The compressive strength behavior of two primary sizes of gravel under C35 concrete specifications, CS1 and CS2, was experimentally examined in this work. The influence of coarse aggregate particle size on compressive strength has been studied in particular. A test on concrete material was also conducted to serve as a reference point. The results revealed that both CS1 and CS2 failed in a fragile manner. The tested specimen's usual failure mechanism is cone and split failure. It was discovered that coarse aggregates with a size of 10/20 mm had a maximum compressive strength of 38.3 MPa. It was also discovered that the size of the coarse particles had no effect on the slump flow trend. The slump flow for CS2 is larger than that of CS1, which contains coarse aggregate sizes of 5/10 mm. Furthermore, the compressive strength of C35 is approximately identical for CS1 and CS2 but infected to the workability under the situation of site pouring concrete. Furthermore, a constitutive model might be used to characterize the influence of particle size on the strength parameters of geopolymer concrete.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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