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THE EFFECT OF DIFFERENT CONCRETE MIX DESIGNS AND MAXIMUM AGGREGATE SIZE VARIATIONS ON THE COMPRESSIVE STRENGTH OF NORMAL CONCRETE

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ABSTRACT: Each component of the material that makes up concrete has a significant influence on its mechanical properties, so a mix design is needed to obtain the optimum concrete quality. This research uses three mix design methods, namely based on SNI 03-2834-2000, SNI 7656:2012, and Dreux Gorisse. SNI 03-2834-2000 refers to the DOE method from the UK, while SNI 7656:2012 adopts the ACI method from America. SNI 03-2834-2000 and SNI 7656:2012 are the applicable methods in Indonesia. While Dreux Gorisse is a concrete mix design method originating from France. This study aims to analyze the effect of concrete mix design and maximum aggregate size variation on the compressive strength of normal concrete. The maximum size of coarse aggregate used was 10, 20, and 40 mm. The planned concrete quality (f'c) was 25 MPa with cylindrical specimens measuring 15x30 cm. The highest compressive strength test results at the age of 28 days are with the SNI 7656:2012 method for a maximum aggregate size of 10 mm at 31.33 MPa. While the lowest compressive strength value with Dreux Gorisse for a maximum aggregate size of 40 mm was 25.38 MPa. In all mix design methods, the smaller the maximum size of coarse aggregate, the higher the compressive strength value. The maximum aggregate size of 10 mm in the SNI 7656:2012 method resulted in an increase in the maximum compressive strength by 25.31% from the planned compressive strength because it has a lower w/c ratio and slump values of 0.49 and 65 mm.

Keywords: Mix Design, Maximum Aggregate Size, Slump Test, Compressive Strength

1. INTRODUCTION

The implementation of infrastructure development is growing rapidly, along with the increasing use of concrete as the main forming component [1]. Concrete is often used in the construction of buildings, roads, bridges, and water structures. Concrete is a mixture of several constituent materials, such as cement, coarse aggregate, fine aggregate, and water, with or without additives [2–4].

Aggregate serves as a filler material with a percentage of 60-70% of the weight of the concrete mix [5]. The gradation of the aggregate will affect the density of the concrete, especially with the use of coarse aggregate [6]. When larger coarse aggregates are used, they create voids between the grains, resulting in large pore volumes and thinner fresh concrete [7]. On the other hand, when using coarse aggregates with small and varied sizes, the small grains will fill the larger grains, the pore volume is small, and the fresh concrete appears denser [8].

The properties and characteristics of concrete constituent materials will affect the mix design. Concrete mix design aims to produce optimal concrete mix proportions with minimum use of constituent materials by considering standard criteria and economic value for making concrete structures [9]. There are several mix design methods originating from home and abroad. For example, SNI 03-2834-2000 and SNI 7656:2012 are applicable in Indonesia. These two methods have different references, SNI 03-2834-2000 refers to the DOE standard from the UK. While SNI 7656:2012 refers to the ACI 211. 1-91 standard, which comes from America [10]. One of the mix design methods from abroad is Dreux Gorisse from France [11]. The Dreux-Gorisse method is a mix design method that uses granulometric analysis, which divides aggregates into several categories according to their size using a series of filters [12].

Foulhudan et al. [13] conducted research on the comparison of mix design SNI 03-2834-2000 and SNI 7656:2012 in terms of the normal concrete casting process. There are 12 casting variations with cylindrical test objects measuring 150 mm x 300 mm. The research review includes testing the compressive strength, tensile strength, and modulus of elasticity of concrete. The results showed that the optimum compressive strength of concrete produced was 43.52 MPa in the casting process with the addition of water at the end of the process (dry mixing) and mix design based on SNI 7656: 2012. However, the tensile strength value of concrete achieved is not optimum at 3.29 MPa, and the elastic modulus value is 10991.89 MPa.

Yulius [10] conducted a comparative study of concrete mix design based on SNI 03-2834-2000 and SNI 7656:2012 at a concrete quality of 20 MPa. The test objects used are cylinders with a size of 150 mm x 300 mm, with as many as 5 test objects for each variation. The results showed that the compressive strengths produced by SNI 03-2834-2000 and SNI 7656:2012 were 21.95 MPa and 23.01 MPa, respectively. These results show that the compressive strength value obtained from the mix design based on SNI 7656:2012 is higher than the compressive strength value of SNI 03-2834-2000.

Leroy et al. [14] conducted a comparative study of the compressive strength of concrete with crushed gneiss, crushed basalt, and alluvial sand as fine aggregate. The mix design method used was Dreux Gorisse. The results of the compressive strength test at 28 days showed that concrete made from crushed basalt produced the highest compressive strength of 34 MPa, followed by concrete made with alluvial sand at 24 MPa, and concrete made from crushed gneiss at 22 MPa.

In terms of the comparison of ACI and DOE, another study was conducted by Zanwar and Jamkar [15] to compare two mix designs of DOE and ACI with different w/c ratios for planning high strength concrete. The w/c values used were 0.35, 0.3, 0.25, and 0.2. The results obtained show that w/c ratios of 0.3, 0.25, and 0.2 get the highest compressive strength using ACI, while w/c ratios of 0.35 get the highest compressive strength when using DOE. Maximum aggregate size and grain gradation affect the behavior of hard concrete due to different pore sizes and concrete density.

Woode et al. [16] investigated the effect of maximum aggregate size (10, 14, and 20 mm) on the strength of structural concrete. The concrete mix used a weight ratio of cement: sand : gravel of 1:2:3 with a cement-water ratio of 0.63. The test specimens were in the form of cubes measuring 150 mm x 150 mm x 150 mm, with as many as 36 specimens. The results concluded that the strength of concrete increases as the maximum size of coarse aggregate decreases. The slump value of 20 mm aggregate was higher than other variations at the same water-cement ratio. Xie et al. [17] also show that the compressive strength of concrete increases when the maximum size of coarse aggregate decreases.

The research of Albarwary et al. [18] used concrete mixtures with a ratio of cement : sand : gravel, including 1:1.5:3, 1:2:4, and 1:3:6. The maximum sizes of coarse aggregate used were 9.5 mm, 12.5 mm, 19 mm, 25 mm, and 37.5 mm. In general, the compressive strength of concrete increased when the maximum size of aggregate was reduced. The test results also showed that the optimum compressive strength was achieved using a maximum aggregate of 9.5 mm.

In contrast to the previous research, this research will compare three mix design methods, namely SNI 03-2834-2000, SNI 7656:2012, and Dreux Gorisse, with variations in the maximum aggregate size of 10, 20, and 40 mm. This study was conducted to determine the amount of concrete material, analyze the level of workability, and determine its effect on compressive strength so as to produce the best quality concrete so that construction work becomes more optimal.

2. RESEARCH SIGNIFICANCE

Concrete mix design must meet the criteria of applicable standards. The significance of this research is to obtain more effective mix proportion data as a consideration in the planning and implementation of building construction using concrete. The purpose of this study are first to identify the amount of normal concrete material required between different mix design methods with varying maximum aggregate sizes. Second, to analyze the relationship between the maximum size of coarse aggregate and the viscosity of concrete. Third, to compare the effect of mix design variation and the maximum size of coarse aggregate on compressive strength.

3. METHODOLOGY

3.1 Testing of Concrete Materials

This research was conducted at the Structures and Construction Materials Laboratory, Department of Civil Engineering, Faculty of Engineering, Siliwangi University. Testing of the materials that make up concrete aims to understand the properties and characteristics of the materials that make up concrete. Apart from that, the testing of materials also functions to analyze the impact of the properties and characteristics of the concrete produced, both in fresh concrete conditions and in concrete that has hardened.

The materials used as concrete mix include: fine aggregate from Galunggung; coarse aggregate from Mangin (maximum size 10, 20, and 40 mm); and type I cement. All materials were collected from Tasikmalaya City. The test results for fine aggregates are as shown in Table 1, and those for coarse aggregates are as shown in Table 2. The test results of fine aggregate and coarse aggregate at a maximum of 10, 20, and 40 mm meet the applicable standards, so it is suitable for use as a concrete mixture.

Table 1 Material properties of fine aggregate

Material Properties	Result
Sieve Analysis	Zone 2
Fineness Modulus	2.81
Specific Gravity (SSD)	2.60
Absorption	2.04 %
Water Content	2.74 %
Solid Fill Weight	1.53 gram/cm^3
Mud Content	2.82 %

Table 2 Material properties of coarse aggregate

Material Properties	Maximum Aggregate Size		
	10 mm	20 mm	40 mm
Fineness Modulus	6.36	6.86	6.88
Specific Gravity (SSD)	2.57	2.58	2.60
Absorption (%)	2.74	2.39	2.04
Water Content (%)	2.39	2.04	1.35
Solid Fill Weight (gram/cm^3)	1.60	1.63	1.65
Strength of Coarse Aggregate (%)	30.12	28.16	26.47

3.2 Concrete Mix Design

The design of concrete mix aims to determine the proportion of each constituent material so that it meets the criteria of workability, strength, durability, and final finish according to specifications [19]. The proportions of the mixture resulting from the mix design process must be optimal, that is, using a minimum of materials in accordance with technical and economic requirements [20].

3.2.1 SNI 03-2834-2000 Method

The SNI 03-2834-2000 method is a procedure for making normal concrete mix plans and is one of the references used to design the proportion of concrete mixes so as to obtain the desired strength [3]. Design steps using SNI 03-2834-2000 with several hypotheses, as follows [10]:

a. This mix design method is applicable to ordinary-use cement (type I), medium-hydration hot cement (type II), fast-hardening cement (type III), and sulfate-resistant cement (type V);
b. This method categorizes between broken (crushed stone) and unbroken (natural aggregate) aggregates, which will affect the water proportion of the concrete mix;
c. Classify the fine aggregate gradation according to the region and assume that the fine aggregate will affect the performance of the concrete mix;
d. The estimated free water content is influenced by the degree of ease required with the planned slump value;
e. The water cement ratio value used was 0.5.

3.2.2 SNI 7656:2012 Method

The SNI 7656:2012 method describes the procedures for selecting mixes for normal concrete, heavy concrete, and mass concrete for various types of cement. SNI 7656:2012 refers to the method ACI 211. 1-91 from America [4]. Design steps using SNI 7656:2012 with several hypotheses, as follows [10]:

a. This mix design method is applicable to all types of cement and types of aggregates;
b. The type of compaction affects the recommended slump value;
c. The stability of the mixture which affects the workability is influenced by the moisture content of the concrete mixture through the slump value;
d. The proportion of coarse aggregate in the concrete mix is affected by the maximum size of the aggregate and the fine modulus of grain value of the fine aggregate;
e. The estimation of fine aggregate content is done on the basis of concrete weight or absolute volume.

3.2.3 Dreux Gorisse Method

This method was initiated by Prof. Georges Dreux from France, so the name of this method is adjusted to the name of the originator. The Dreux method [11] explains that the average compressive strength at 28 days is influenced by several factors, including the compressive strength of cement, the granular factor (compactness of aggregate grains), and C/E is the ratio of cement weight to water weight. Cement in French is ciment (C), while water is eau (E). As in the formula below.

$$f'cr = G \times fce \times \left(\frac{C}{E} - 0.5 \right) \tag{1}$$

Where :

f'cr = average compressive strength at 28 days (MPa)
G = granular factor
fce = cement compressive strength (MPa)
C = cement weight (kg/m^3)
E = water weight (kg/m^3)

Table 3 Granular Factor

Quality Granules	Maximum Aggregate Size (mm)		
	Small (D ≤ 16)	Medium (25 ≤ D ≤ 40)	Large (D ≥ 63)
Excellent	0.55	0.60	0.65
Normal	0.45	0.50	0.55
Wearable	0.35	0.40	0.45

3.3 Concrete Compressive Strength Testing

The compressive strength is the ability of concrete to accept a compressive force of unity area as per Eq. (2). The compressive strength of concrete increases in value with age. The strength of concrete will increase rapidly until the age of 28 days, but after that the increase in compressive strength of concrete becomes slow. The compressive strength test aims to identify the quality of concrete test specimens with a Compression Testing Machine (CTM) tool referring to SNI 1974-2011. The higher the strength of the building structure, the higher the quality of the concrete produced.

$$f'c = \frac{P}{A} \quad (2)$$

Where :

f'c = compressive strength of concrete (MPa)
P = axial compressive force (N)
A = test surface area (mm^2)

The concrete to be made in this study is cylindrical, with a diameter of 15 cm and a height of 30 cm. The planned concrete compressive strength (f'c) is 25 MPa for column construction that is indoors without additional air. The concrete mix design uses the SNI 03-2834-2000, SNI 7656:2012, and Dreux Gorisse methods. This study used variations in the maximum coarse aggregate size consisting of sizes 10, 20, and 40 mm. The number of test specimens was 81 for testing the compressive strength of concrete at the ages of 7, 14, and 28 days. So that each research variation at each age of compressive strength testing as many as 3 specimens.

4. RESULT AND DISCUSSION

4.1 Mix Design Calculation Results

The concrete mix design is done after all the data from the testing of the constituent materials is generated. From these data, it can be determined the proportion of material required between cement, fine aggregate, coarse aggregate, and water in the concrete mixture with the planned quality.

4.1.1 Material Requirements on SNI 03-2834-2000 Method

Recapitulation of material requirements in the SNI 03-2834-2000 method with variations in the maximum size of aggregates in SSD (Saturated Surface Dry) conditions as shown in Table 4.

Table 4 Material Requirements on Each of All Research Variations

Code	Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Weight of Concrete (kg/m^3)	w/c Ratio	C/E Ratio
S00-10	233.33	466.67	789.53	805.48	2295.00	0.50	-
S00-20	205.00	410.00	683.35	1046.65	2345.00	0.50	-
S00-40	185.00	370.00	637.00	1183.00	2375.00	0.50	-
S12-10	228.00	461.73	854.48	735.80	2280.00	0.49	-
S12-20	205.00	415.15	714.77	1010.08	2345.00	0.49	-
S12-40	181.00	366.55	692.11	1170.35	2410.00	0.49	-
Drx-10	230.18	457.80	806.49	863.62	2358.09	0.50	1.99
Drx-20	213.09	408.89	698.27	1039.35	2359.61	0.52	1.92
Drx-40	203.48	374.40	624.28	1159.38	2361.54	0.54	1.84

Table 5 Percentage Change in Concrete Mix Material Requirements

Code	Water (%)	Cement (%)	Fine Aggregate (%)	Coarse Aggregate (%)	Weight of Concrete (%)	w/c Ratio (%)	C/E Ratio (%)
S00-10	0.00	0.00	0.00	0.00	0.00	0.00	-
S00-20	-12.14	-12.14	-13.45	29.94	2.18	0.00	-
S00-40	-20.71	-20.71	-19.32	46.87	3.49	0.00	-
S12-10	0.00	0.00	0.00	0.00	0.00	0.00	-
S12-20	-10.09	-10.09	-16.35	37.28	2.85	0.00	-
S12-40	-20.61	-20.61	-19.00	59.06	5.70	0.00	-
Drx-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drx-20	-7.42	-10.68	-13.42	20.35	0.06	3.65	-3.52
Drx-40	-11.60	-18.22	-22.59	34.25	0.15	8.09	-7.49

Based on the analysis of the Table 5, it is found that as the maximum size of coarse aggregate increases (10 mm, 20 mm, and 40 mm), there is an increase in the proportion of coarse aggregate and concrete weight by (0%, 29.94%, 46.87%) and (0%, 2.18%, 3.49%), respectively. On the contrary, the decrease in the proportion of water, cement, and fine aggregate was (0%, -12.14%, -20.71%), (0%, -12.14%, -20.71%), and (0%, -13.45%, -19.32%) respectively.

According to SNI 03-2834-2000 [3], one of the factors affecting the water proportion of concrete mixtures is the maximum size of the aggregate. The larger the maximum size of the coarse aggregate, the less the water proportion of the concrete mix. All variations of coarse aggregate size using the SNI 03-2834-2000 method resulted in the same w/c ratio of 0.5. In SNI 03-2834-2000, the w/c ratio is influenced by the type of cement, the type of coarse aggregate, the average compressive strength at 28 days, and the shape of the specimen. The value of the cement water factor used is not affected by the maximum size of the coarse aggregate.

The proportion of cement is obtained from the proportion of water divided by the w/c ratio. The w/c values are similar for all coarse aggregate sizes. As the maximum size of the aggregate increases, the proportion of water will decrease along with the proportion of cement. The ratio of fine aggregate to coarse aggregate is influenced by slump value, fine aggregate gradation, w/c ratio, and the maximum size of coarse aggregate. The larger the maximum size of coarse aggregate, the smaller the percentage of fine aggregate and the larger the percentage of coarse aggregate.

4.1.2 Material Requirements on SNI 7656:2012 Method

Based on the analysis results from the Table 4, it is known that the material requirements of concrete with the SNI 7656:2012 method in SSD aggregate condition are related in that with the larger maximum size of coarse aggregate (10 mm, 20 mm, and 40 mm), there is an increase in the proportion of coarse aggregate and concrete weight by (0%, 37.28%, 59.06%) and (0%, 2.85%, 5.70%). On the contrary, the decrease in the proportion of water, cement, and fine aggregate was (0%, -10.09%, -20.61%), (0%, -10.09%, -20.61%), and (0%, -16.35%, -19.00%) respectively as shown in Table 5.

According to SNI 7656:2012 [4], the estimated water content in concrete mixtures is influenced by the maximum size of the aggregate, the type of concrete with or without added air, and the slump value. The larger the maximum size of the aggregate, the smaller the proportion of water used. The w/c value for all coarse aggregate size variations is the same at 0.49. In SNI 7656:2012, the value of w/c is influenced by the average compressive strength at 28 days and the type of concrete with or without added air. The value of the cement water factor used is not affected by the maximum size of coarse aggregate.

The proportion of cement is obtained from the proportion of water divided by the w/c ratio. The w/c values are similar for all coarse aggregate sizes. As the maximum size of the aggregate increases, the proportion of water decreases as the proportion of cement decreases. The volume of coarse aggregate in a concrete mix is affected by the maximum size of the aggregate and the fineness modulus value of the fine aggregate. The larger the maximum size of the aggregate, the larger the proportion of coarse aggregate in the concrete mix. On the contrary, the proportion of fine aggregate decreases.

The proportion of fine aggregate in S12-10 is higher than the proportion of coarse aggregate, because according to SNI 7656:2012 [4], it shows the relationship that the smaller the maximum size of the aggregate and the larger the fine modulus of fine aggregate grains, the smaller the volume of coarse aggregate per unit volume of concrete.

4.1.3 Material Requirements on Dreux Gorisse Method

Based on the analysis results from the Table 4, it is known that the material requirements of concrete with the Dreux Gorisse method in SSD aggregate condition are related in that with the larger maximum size of coarse aggregate (10 mm, 20 mm, and 40 mm), there is an increase in the proportion of coarse aggregate and concrete weight by (0%, 20.35%, 34.25%) and (0%, 0.06%, 0.15%). On the contrary, the decrease in the proportion of water, cement, and fine aggregate was (0%, -7.42%, -11.60%), (0%, -10.68%, -18.22%), and (0%, -13.42%, -22.59%) respectively as shown in Table 5.

According to Dreux Gorisse [11], the proportion of cement is influenced by the slump value and the C/E value (the ratio of cement weight to water weight). The larger the maximum aggregate size, the lower the C/E value, while the slump value is the same for all coarse aggregate size variations. The smaller the C/E value, the lower the proportion of cement in the concrete mix. The water used in the concrete mix will be corrected according to the maximum size of the aggregate used. The proportion of water will be less as the maximum size of the aggregate increases. The proportion of fine aggregate and coarse aggregate is determined based on granulometric analysis. The larger the maximum size of the aggregate, the more gentle the curve of the benchmark will be. So the proportion of fine aggregate will be less, and the proportion of coarse aggregate will be more. The w/c value increases, indicating that the fresh concrete appears thinner as the maximum aggregate size increases.

4.2 Slump Test Results

Slump testing aims to determine the level of viscosity and ease of working of fresh concrete. Slump testing is carried out based on SNI 1972:2008. The slump value requirement in SNI 03-2834-2000 is between 60 - 180 mm, the slump value in the SNI 7656:2012 method should be between 50 - 125 mm, while the slump value requirement in Dreux Gorisse is between 100 - 130 mm. The slump test results, as shown in Fig. 1, for all mix design methods with varying maximum aggregate sizes meet the specified requirements.

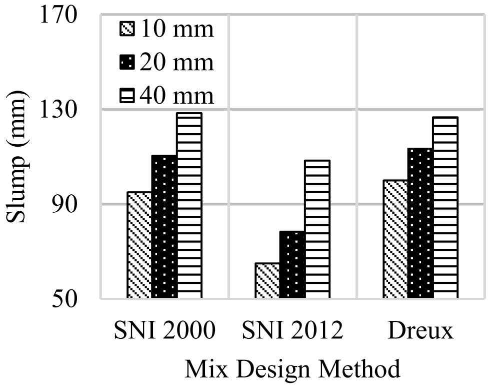

Fig. 1 Slump Test Results in Each Research Variation

The slump values for the SNI 03-2834-2000 method with maximum aggregate size variations (10 mm, 20 mm, and 40 mm) are 95 mm, 110.33 mm, and 128.33 mm, respectively. In the SNI 7656:2012 method, the maximum aggregate size variations (10 mm, 20 mm, and 40 mm) are 65 mm, 78.33 mm, and 108.33 mm respectively. While in Dreux Gorisse method with maximum aggregate size variation (10 mm, 20 mm, and 40 mm) are 100 mm, 113.33 mm, and 126.67 mm respectively.

Based on the analysis of Fig. 1, all mix design methods show that the slump value with a larger maximum aggregate size causes the pore volume in the concrete to be larger, so it has a high workability value, and the fresh concrete is thinner [16,21,22]. The use of larger aggregate maximum grains makes the fresh concrete mix easier to work with than smaller maximum grains [7]. Conversely, the slump value of concrete with smaller maximum aggregate sizes causes the pore volume in the concrete to be smaller, and the fresh concrete mix appears denser, resulting in a low workability value.

4.3 Compressive Strength Test Results

Compressive strength testing was carried out at the ages of 7, 14, and 28 days to analyze the results of concrete compressive strength based on the length of concrete age and the effect of different mix design methods and variations in maximum aggregate size on concrete compressive strength.

4.3.1 Compressive Strength Results on SNI 03-2834-2000 Method

The compressive strength value of concrete as in the SNI 03-2834-2000 method with a maximum aggregate of 10 mm at the age of 7 days was 18.68 MPa, the age of 14 days was 27.27 MPa, and the age of 28 days was 30.29 MPa. The compressive strength value in SNI 03-2834-2000 with a maximum aggregate of 20 mm at the age of 7 days was 18.02 MPa, the age of 14 days was 25.10 MPa, and the age of 28 days was 28.31 MPa. While the compressive strength value in SNI 03-2834-2000 with a maximum aggregate of 40 mm in 7 days amounted to 16.80 MPa, 14 days of age amounted to 23.02 MPa, and 28 days of age amounted to 25.57 MPa, as shown in Fig. 2. Thus, the compressive strength of SNI 03-2834-2000 increases when the maximum aggregate size is smaller.

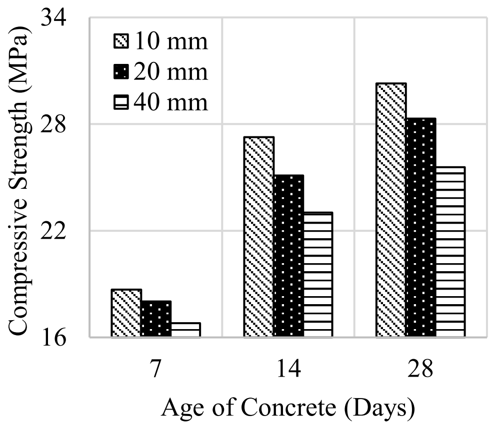

Fig. 2 Compressive Strength Results on SNI 03-2834-2000 Method

4.3.2 Compressive Strength Results on SNI 7656:2012 Method

The compressive strength value of concrete as in the SNI 7656:2012 method with a maximum aggregate of 10 mm at the age of 7 days is 20.10 MPa, the age of 14 days is 29.25 MPa, and the age of 28 days is 31.33 MPa. The compressive strength value in SNI 7656:2012 with a maximum aggregate of 20 mm at the age of 7 days was 18.12 MPa, age 14 days was 25.76 MPa, and age 28 days was 29.25 MPa. While the compressive strength value in SNI 7656:2012 with a maximum aggregate of 40 mm at the age of 7 days amounted to 17.08 MPa, age 14 days amounted to 23.31 MPa, and age 28 days amounted to 26.14 MPa, as shown in Fig. 3. The compressive strength result in SNI 7656:2012 increases when the maximum aggregate size is smaller.

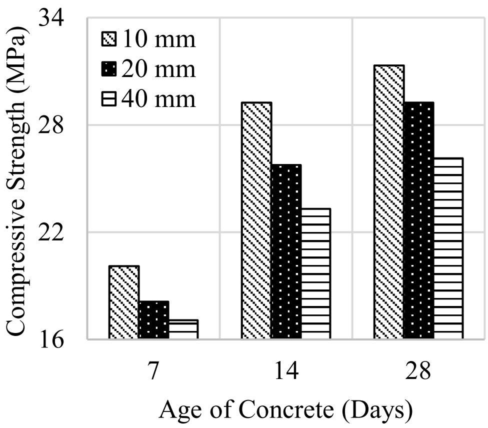

Fig. 3 Compressive Strength Results on SNI 7656:2012 Method

4.3.3 Compressive Strength Results on Dreux Gorisse Method

The compressive strength value of Dreux Gorisse Method concrete with a 10 mm aggregate maximum at 7 days was 18.59 MPa, 14 days was 26.52 MPa, and 28 days was 29.54 MPa. The compressive strength value of Dreux Gorisse with a maximum aggregate of 20 mm at 7 days was 17.46 MPa, 14 days was 24.82 MPa, and 28 days was 28.12 MPa. While the compressive strength value of Dreux Gorisse with a maximum aggregate of 40 mm at 7 days was 16.70 MPa, 14 days was 22.74 MPa, and 28 days was 25.38 MPa, as shown in Fig. 4. Thus, the compressive strength of Dreux Gorisse increases when the maximum aggregate size is smaller.

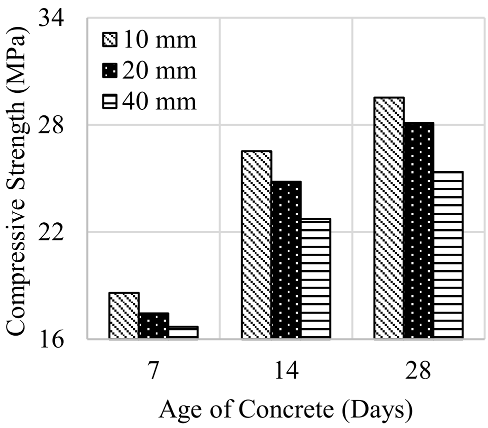

Fig. 4 Compressive Strength Results on Dreux Gorisse Method

4.4 Analysis of Compressive Strength Results

The compressive strength test results of all study variations met the plan compressive strength of 25 MPa. All mix design methods produce higher compressive strength when the maximum aggregate size is smaller. This is because the porous volume is smaller and the fresh concrete is denser when the smaller coarse aggregate grains fill the voids between the larger aggregate grains in the concrete. This is in accordance with the results of research by Woode et al. [16], Xie et al. [17], and Albarwary et al. [18].

Conversely, the strength of concrete decreases when larger coarse aggregates are used. The pore volume in concrete is higher because the larger aggregate grains will form voids in the concrete. According to Professor Arthur N. Talbot in Mulyono [5], the relationship is that the number of pores in the aggregate gets higher as the number of pores in the concrete gets higher, but the compressive strength of the concrete decreases.

Aggregate gradation is one of the factors that affects the compressive strength of concrete [23]. A good arrangement of aggregate grains will result in maximum density and minimum porosity. A good gradation used in concrete mixtures is a continuous gradation, where the varying grain sizes fill the empty voids according to the grain size [24,25].

The higher compressive strength for all variations in the maximum size of coarse aggregate is the SNI 7656:2012 method. Compared to other variations, the fresh concrete mix in the SNI 7656:2012 method has a lower w/c ratio and is denser in terms of slump value. Then followed SNI 03-2834-2000, and the Dreux Gorisse method produces lower compressive strength. The water cement ratio value in SNI 7656:2012 is 0.49. The SNI 03-2834-2000 method uses a w/c ratio of 0.5. While in Dreux Gorisse, the w/c ratio is 0.50, 0.52, and 0.54, respectively. As shown in Fig. 5, the maximum aggregate size of 10 mm in the SNI 7656:2012 method results in an increase in the maximum compressive strength of 25.31% of the plan compressive strength.

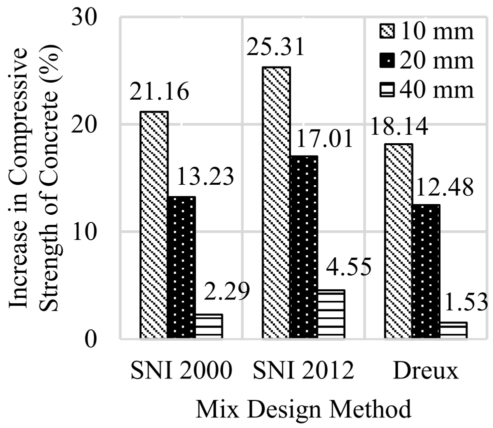

Fig. 5 Increase in Compressive Strength of Concrete at 28 Days

Tjokrodimuljo [7] stated that the commonly used w/c ratio is in the range of 0.4 to 0.6. The compressive strength is higher and the density of the concrete is higher if the w/c ratio value used is lower [26,27]. Cement paste is more widely used for concrete with a low w/c ratio. When the cement paste fills all the pores and surfaces between the aggregates completely, it will work well [28].

The strength of concrete decreases with a high w/c value because workability also increases [29, 30]. Less cement paste is used for concrete mixes with higher w/c ratios. The bond between the cement paste and the aggregate becomes weak, and the compressive strength of the concrete decreases as a result of the cement paste not being enough to cover the entire surface of the aggregate and fill the voids between the aggregate grains.

5. CONCLUSION

In the SNI 03-2834-2000, SNI 7656:2012, and Dreux Gorisse methods, the relationship shows that the larger the maximum size of coarse aggregate, the higher the proportion of coarse aggregate and the weight of concrete. However, the proportion of water, cement, and fine aggregate decreases. The w/c ratio values in SNI 03-2834-2000 and SNI 7656:2012 are fixed because they are not affected by the maximum size of the coarse aggregate. Meanwhile, the w/c ratio in Dreux Gorisse increases because the larger the maximum size of the coarse aggregate.

The slump value with a larger maximum aggregate size causes the pore volume in the concrete to be larger, and the fresh concrete mix appears thinner and thus has a high workability value. In the compressive strength test results for concrete aged 28 days, the highest compressive strength value in SNI 7656:2012 for the maximum aggregate size of 10 mm was 31.33 MPa. Meanwhile, the lowest compressive strength value for Dreux Gorisse with a maximum aggregate size of 40 mm is 25.38 MPa. All mix design methods yielded higher compressive strengths when the maximum size of the aggregate was smaller, as it has a smaller pore volume, resulting in a higher density. The maximum aggregate size of 10 mm in the SNI 7656:2012 method results in an increase in the maximum compressive strength of 25.31% of the planned compressive strength because it has a lower w/c ratio and slump values of 0.49 and 65 mm.

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