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EFFECT OF MICRO-SCALED SIZE OF SAND ON CONCRETE SOLIDITY AND COMPRESSIVE STRENGTH

HILMI AULAWI[1,*], I. FARIDA[2], ASEP BAYU DANI NANDIYANTO[3], CEP UBAD ABDULLAH[4], ISMA WIDIATY[5]

[1]Department of Industrial Engineering, Sekolah Tinggi Teknologi Garut
Jl. Mayor Syamsu No. 1, Garut, Indonesia
[2]Department of Civil Engineering, Sekolah Tinggi Teknologi Garut
Jl. Mayor Syamsu No. 1, Garut, Indonesia
[3]Departemen Kimia, Universitas Pendidikan Indonesia
Jl. Dr. Setiabudi no 229, Bandung, 40154, Indonesia
[4]Program Studi Pendidikan Pariwisata, Universitas Pendidikan Indonesia
Jl. Dr. Setiabudi no 229, Bandung, 40154, Indonesia
[5]Departemen Pendidikan Kesejahteraan Keluarga, Universitas Pendidikan Indonesia
Jl. Dr. Setiabudi no 229, Bandung, 40154, Indonesia
*Corresponding Author: hilmi_aulawi@sttgarut.ac.id

Abstract

This study aimed to investigate the effect of particle size of fine aggregate on concrete solidity and compressive strength. In addition, this study also analyzed several factors that influenced mechanical strength properties of concrete. Experiments were done by testing two types of fine aggregates with different particle sizes (*i.e.*, 1200 and 800 μm). In the experimental procedure, we mixed water, sand (consisting of both coarse and fine aggregates), and Portland cement in a batch-typed mixing drum. The results showed the 800-μm fine aggregates had better performance in terms of concrete solidity and compressive strength compared to that with 1200-μm fine aggregates. Effects of concrete lifetime on compressive strength were also examined. 28 days of aging process gave the maximum compressive strength for both fine aggregates. However, the concrete produced by 800-μm fine aggregates had better solidity and compressive power than that by 1200-μm fine aggregates. When the concrete was packed, the smaller aggregates were able to penetrate in the deepest position of space within coarse aggregates. This results demonstrated the importance of aggregate sizes for further development of building and concrete production.

Keywords: Fine aggregate, Sand, Concrete, Compressive strength, Education.

1. Introduction

Concrete consists of a mixture of coarse and fine aggregates, Portland cement, and water [1]. To make concrete with good quality, the total amount of aggregates in the concrete total volume should range from 65 to 75%. Therefore, aggregates play an important role in creating good solidity and compressive strength of concrete [2]. Fine aggregates are a material appearing in particles whose size ranges from 0.062 to 2 mm (62-2000 μm) [3].

Several studies have been conducted to determine the optimum condition for producing concrete [4-11]. Of the existing factors influencing the optimum concrete, the size of aggregates plays an important role. In short, a combination of coarse and fine aggregates is mandatory. Specifically, coarse aggregate size must range from 40 to 150 mm (40000 to 150000 μm). In the meantime, fine aggregate size is ranging from 0.062 to 2 mm (62 to 2000 μm) in size [12]. However, until now, there are few studies discussing comparison of different sizes of the fine aggregate. In fact, understanding size of aggregates can affect the production of excellent performance of concrete. Here, the purpose of the study was to analyze the effect of different sizes of fine aggregate towards the solidity and compressive strength of concrete. Furthermore, this study discussed the factors influencing the strength of concrete as well.

2. Materials and Methods

The concrete mixture consisted of Portland cement, water, fine aggregate, and coarse aggregate. All the materials were purchased from PT Rumah Publikasi Indonesia, Indonesia, and used without prior purification. There were two types of fine aggregates used: 800 (namely Cilopang sand) and 1200 μm (namely Leles sand).

Two different mixes were used to evaluate the effect of incorporating fine aggregate size on the solidity and strength of the concrete. Detailed information of the mixes was presented in Table 1. To produce concrete, all materials were put into a specific mixing drum (1-L stainless steel drum) and mixed at the temperature of 25°C for about fifteen minutes. The mixing process was done at 75 rpm. After all materials were mixed up, the wet concrete was produced and put into cylindrical castings (inner dimensions of 30 and 15 cm for height and diameter, respectively). Finally, the mixed materials were dried at room temperature. As a standard comparison, we also mixed a concrete without additional fine aggregates (Sample number M00).

For testing the solidity and compressive strength of the concrete, the dried concrete was characterized using a standard analysis at the laboratory of Sekolah Tinggi Teknologi Garut, Indonesia. For the comparison, each concrete sample was tested at several days after treatment of water soaking.

Table 1. Detailed information of concrete mixes (kg/m^3).

Sample number	Cement	Water	Coarse aggregate	Fine aggregate
M00 (with no fine aggregate)	372.73	205	925.33	-
M01 (800 μm)	372.73	205	925.33	683.94
M02 (1200 μm)	372.73	205	925.33	683.94

3. Results and Discussion

3.1. Physico-chemical properties of aggregate raw materials

Table 2 shows the laboratory test results of all types of aggregates used in this study. Three types of aggregates were analyzed in this study. One is coarse aggregate sample and the others are two types of fine aggregates (800 and 1200 μm). The types of tests conducted in this study were friability volume weight (kg/L), solidity volume weight (kg/L), water content (%), water absorption (%), sludge levels (%), bulk specific gravity (SSD), organic level (color), and solidity index (%). All analysis results were compared with the standardized analysis based on ASTM. As shown in the table, it was found that the analysis results of raw materials are near those of the test standards.

Table 2. Laboratory test results of aggregates.

No.	Type of Aggregate	Tested material	Type of test	Test results	Test standardization
1	Coarse aggregate	Gravel	Friability volume weight (kg/L)	1.323	1.60 – 1.90
			Sodility volume weight (kg/L)	1.809	-
			Water level (%)	3.23	0.50 - 2.00
			Water absorption (%)	3.10	0.20 - 4.00
2	Fine aggregate	800-μm fine aggregates	Friability volume weight (kg/L)	1.289	1.40 - 1.90
			Sodility volume weight (kg/L)	1.882	-
			Water level (%)	3.93	3.00 - 5.00
			Sludge level (%)	2.80	0.20 - 6.00
			Water absorption (%)	10.00	0.20 - 2.00
			Bulk Spesific Gravity (SSD)	2.44	2.40
			Organic level (color)	No.2	< No. 3
			Index of solidity (%)	1.90	2.20
3	Fine aggregate	1200-μm fine aggregates	Friability volume weight (kg/L)	1.530	1.40 - 1.90
			Sodility volume weight (kg/L)	1.938	-
			Water level (%)	1.611	3.00 - 5.00
			Sludge level (%)	4.76	0.20 - 6.00
			Water absorption (%)	8.00	0.20 - 2.00
			Bulk Spesific Gravity (SSD)	2.33	2.40
			Organic level (color)	No. 3	< No. 3
			Index of solidity (%)	1.86	2.20

Tables 3, 4, and 5 are the analysis results of particle size distribution for each type of the aggregates, which was compared to standard size analysis for aggregate (SPEC ASTM C33-90).

The particle sizes of coarse aggregate (see Table 3) range from 2.38 to 25 mm (2380 to 25000 μm). Particle sizes with the most percentage of mass are 9.5 and 19 mm. The average size of this type of aggregate was 11 mm (11000 μm). This is the ideal size of coarse aggregate, particularly for concrete.

Table 4 shows the size distribution of fine aggregate (800 μm) of Cilopang sand. The range of the size laid from 0.075 to 4.75 mm (75 to 4750 μm). There is no particle with the sizes of more than 9.5 mm (9,500 μm) because it showed 0% of its performance of the mass. The analysis of average size showed that the size was at its best performance when it was as big as 0.015 mm (15 μm) since it reached the highest percentage (17%). However, this did not have too significant effect since all the percentages were almost in the same line (ranging from 7% to 17%). The average size of this type of fine aggregate was 0.866 mm (866 μm) which is in a good agreement with this type of aggregate in the market. This size is considered ideal for fine aggregate as part of concrete mixture.

The other type of fine aggregate (namely Leles sand) was explained in Table 5. The table mainly discussed its particle size distribution. It was found that the size for this type of aggregate ranged from 0.075 to 9.50 mm (equal to 75 to 9500 μm). In terms of performance, the aggregate in the size of 0.6 mm (600 μm) appeared to be the best since it has the highest percentage (18%). The average size of the aggregate was 1.219 mm which is equal to 1219 μm. this size is also classified as an ideal size of fine aggregate for making good concrete.

Table 3. Size distribution of coarse aggregate.

Particle size (mm)	Mass percentage (%)
25	5.50
19	33.30
9.50	31.30
4.75	8.70
2.38	6.00
< 0.075	15.20

Table 4. Particle size distribution of Cilopang fine aggregate.

Particle size (mm)	Mass percentage (%)
9.50	0
4.75	7
2.36	12
1.18	10
0.60	12
0.30	13
0.015	17
0.075	14
<0.075	15

Table 5. Particle size distribution of Leles fine aggregate.

Particle size (mm)	Mass percentage (%)
9.50	1
4.75	8
2.36	16
1.18	16
0.600	18
0.300	13
0.015	13
< 0.075	15

3.2. Analysis results of concrete compressive strength test

In order that the concrete produce is in accordance with the minimum requirement for industrial and commercial use, an analysis of strength was done (see Tables 6 and 7). For the test of compressive strength, we used the standard of FC 25 MPa. In other words, the concrete was compressed at 25 MPa. We compared the results of compressive strength test for two types of fine aggregates (one is 800 μm in size and the other is 1200 μm in size). Moreover, we also compared the concrete which had been through an aging process for 7, 14, and 28 days.

Table 6 shows the results of concrete compressive strength containing the 800-μm fine aggregate. The test was done by varying the types of the compressive force. For the samples aged for 7 days, the compressive force was at 14 MPa. This indicates that force only reaches 57% of the standard force. By adding the aging process into 14 days, there is an increase of compressive force as much as 8 MPa so that the final force reached by the samples in this aging process was 22 MPa. In other words, 80% of the standard concrete compressive power was reached.

To get maximum results, the aging process was extended into 28 days which resulted in the increase of compressive force which reached 27 MPa. This force exceeded the minimum standard for concrete compressive power (25 MPa). From this analysis results, it can be concluded that to have optimum compressive power of concrete, the concrete consisting of 800-μm fine aggregate had to go through an aging process for 28 days.

Table 6. Results of concrete compressive power test (25 MPa) of 800-μm fine aggregate.

Age of concrete (day)	Average of compressive power (MPa)	Average (%)
7	14	57
14	22	86
28	27	107

The results of concrete compressive power test for the 1200-μm fine aggregate was presented in Table 7. The results actually resembled the trends acquired from the same test using 800-μm fine aggregate. The longer the age of the concrete was, the more solid and compressively powerful the concrete turned out to be. Thus, in this study, the maximum quality of the concrete was obtained after a 28-day aging process.

From the comparison between the results in Table 6 and those in Table 7, it can be concluded that the concrete consisting of 1200-μm fine aggregate had better solidity on the 7th day. On the 14th day, the performance showed no difference. On the 28th day, the concrete showed maximum quality of its solidity and compressive power. However, the power of the concrete of the 800-μm fine aggregate outperformed that of the 1200-μm fine aggregate on the 28th day. This phenomenon occurs because concrete with fine aggregate has smaller particles which enables them to get in the pores within the coarse aggregate. Indeed, this will create concrete to have more solid and have less porosity [13].

Table 7. Results of concrete compressive power test (25 MPa) of 1200-μm fine aggregate.

Age of concrete (day)	Average of compressive power (MPa)	Average (%)
7	19	77
14	22	88
28	25	100

Fig. 1 shows correlation between concrete lifetime and compressive strength. As shown in the figure, both types of concretes were in the same trend, in which the longer concrete lifetime allows better compressive strength. Based on the Fig. 1, it can be concluded that the 1200-μm fine aggregate sample has higher compressive strength than 800-μm sample when the concrete lifetime is less than 14 days. The main reason for this condition is because 1200-μm fine aggregates have more void spaces. Thus, the longer concrete lifetime can allow faster drying and evaporation of water from the concrete. Indeed, the less amount of water can create stronger material.

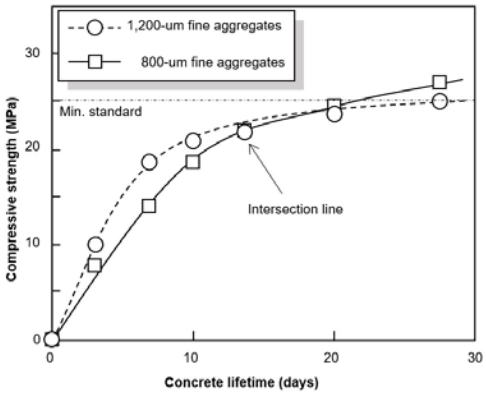

Fig. 1. Correlation between concrete lifetime and compressive strength.

The compressive strength is important to maintain the material structure [14- 16]. The strength of both types of concretes must meet intersection position when the concrete lifetime reached 14 days. Then, after near to 30 days, the 800-μm concrete has higher compressive strength. It can be concluded that the 30 days is appropriate to remove all water components from the concrete. Indeed, when all water components have been removed, the concrete can get its maximum strength performance. The 800-μm aggregates can lead better strength concrete than the 1200-μm one. This is in a good agreement with the above hypothesis that the smaller aggregates can form more compact concrete, lesser void space and porosity in the final concrete, and better mechanical strength properties. This analysis is in a good agreement with previous studies [13].

In addition to the particle size of aggregate, there are other factors influencing the power of concrete such as sludge level, water level, organic level, water absorption, saturated surface dry, and index of solidity. Therefore, we did an analysis of those factors.

3.2.1. Water level

Water is one of the materials that can be used to dissolve the components in cement so that they will be in contact with aggregates. The dissolved components will become ion molecules functioning as a paste among coarse aggregates, among fine aggregates, and between coarse and fine aggregates. However, water will be trapped in between the dissolved ions. In producing concrete, there needs to be drying process to remove the water. If there is no water, the cement will not function as ions pasting aggregates. However, too much water will also cause trouble since the removed water will be pores so that porosity is likely to carry out. For this case, the water composition should be at its optimum capacity. In this study, the amount of water is fixed at a certain point which is categorized optimum (see Table 1). As shown in Table 2, the amount of water in aggregate is quite low leading to the premise that water does not have a significant influence towards the solidity of concrete.

3.2.2. Sludge Level

Sludge is a material absorbing a lot of water so that the mixing of concrete could change. This leads to a tendency of the used of increased water. The added water towards the concrete mixture will diminish the concrete solidity. After the concrete is getting solid, the sludge, which directly contacts with water through the concrete pores will expand and shrink within the concrete. This will eventually cause the concrete to be more fragile.

Studies proved that the level of sludge affects the power and solidity of concrete. The less sludge in concrete mixture, the stronger the concrete will get. On the other hand, concrete with too much sludge will have less power and solidity since the paste will not work effectively. The sludge will block the mixing of cement and aggregate. Thus, in this case, more cement is needed to paste the surface of each aggregate type. Table 1 presents that the sludge level used in every type of aggregate is not too different. This indicated that the level of sludge does not have a significant influence towards the concrete solidity [17].

3.2.3. Organic level

In general, the organic level can actually decrease the solidity and power of concrete since too much organic level will destroy concrete power and solidity. Such organic contents as oil, fat, glucose, and slat mixed with cement on concrete mixture will affect the cement hydration and slow down the solidification process of the concrete. Table 1 shows that the organic level on the aggregate test has color in accordance with the standard test of ASTM.

3.2.4. Aggregate pore condition

Aggregate pores impact how much water is dissolvable. In the process of mixing cement and aggregates, the pores expand the possibility of ion absorption from cement and strengthen their paste among them. However, when the cement is dried, the pores can be a serious issue. The pores which no longer contains water (after the drying process) will be able to absorb water from the air. It is believed that the nature of water is closely related to concrete porosity and absorption. The concrete endurance towards its environment is determined by the level of water absorption. The high value of absorption on concrete indicates that the concrete has low durability. This is logically due to the fact that high absorption level leads to concrete power degradation. The results in Table 1 showed that coarse aggregate has low water absorption level (2%). On the other hand, fine aggregate has higher percentage of water absorption level (10%). Since both 800 and 1200-μm fine aggregate has almost equal percentage, this factor is not taken into consideration due to its lack of significant impact.

3.2.5. Saturated surface dry

A good aggregate used in the mixture of concrete is that in saturated surface dry (SSD) condition. Aggregates which have not reached the SSD condition will tend to absorb water when the water has not reacted well with the cement. This causes the lack of water in the concrete mixture. Unfortunately, this phenomenon affects the power and solidity of the concrete as well. From the analysis results presented in Table 1 regarding SSG, it was found that the value of SSD for both fine aggregates was quite equal. Therefore, it can be concluded that SSD does not have a significant influence on the concrete solidity.

3.2.6. Index of solidity

The last factor influencing the solidity and power of concrete is index of solidity of the aggregate. This index affects the total solidity of concrete. The more solid the index of solidity of the aggregate, the more solid the concrete will get as well. On the contrary, the lower the aggregate solidity index gets, the more fragile the concrete produced will be. However, all types of aggregates (both coarse and fine aggregates) should have identical index of solidity. Table 1 shows that two fine aggregates have almost the same index of solidity so that this index is not one of the significant factors in influencing the power and solidity of the concrete.

4. Conclusions

Effects of fine aggregate size in the micron scale on the compression strength of concrete have been examined. Two sizes of fine aggregates were used, *i.e.*, 800 and 1200 μm. Experimental results confirm that the use of smaller aggregates has a great impact on the improvement of compression strength. This is because the smaller fine aggregates can fill the deeper spaces between the coarse aggregates, creating stronger concrete.

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