TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Homepage jurnal: http://jurnal.untirta.ac.id/index.php/ju-tek/

Superplasticizer and hydrated lime for high-strength concrete

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ARTICLE INFO

Article history:
Submitted 27 July 2022
Received 29 August 2022
Received in revised form 30 November 2022
Accepted 23 June 2023
Available online on 30 June 2023

Keywords:
Concrete, Compressive Strength, Admixture, Hydrated lime.

Kata kunci:
Beton, Kuat Tekan, Admixture, Kapur Padam.

ABSTRACT

According to SNI03-6468-2000, high-strength concrete is concrete with a minimum compressive strength of 41.4 MPa. The high strength concrete is useful in precast and prestressed concrete. This study aimed to find the effect of using superplasticizer and hydrated lime on the compressive strength of high-strength concrete K-500 when reviewed at the age of 3, 7, 14, and 28 days. This study used several percentages of superplasticizer for high-strength concrete mixtures, namely the proportions of 0%, 1%, 2%, and 3%. As for the hydrated lime that was tested, the percentages were 0%, 5%, 15% and 25%. The results of the compressive strength test of K-500 concrete without superplasticizer and hydrated lime at the age of 3, 7, 14 and 28 days respectively were 208 kg/cm2, 347 kg/cm^2, 462 kg/cm^2, and 525 kg/cm^2. This results has met the requirements for compressive strength of K-500. Using of 1% to 3% superplasticizer with 5% of hydrated lime at the age of 28 days, the compressive strength obtained were 698.67 kg/cm2, 668.89 kg/cm2, and 465.48 kg/cm2. The compressive strength of using 1% to 3% of superplasticizer with 15% of hydrated lime at the age of 28 days were 508.89 kg/cm2, 473.33 kg/cm^2, and 359.70 kg/cm^2. As for the compressive strength of using 1% to 3% superplasticizer with 25% of hydrated lime at the age of 28 days were 320.00 kg/cm^2, 300.44 kg/cm^2, and 254.22 kg/cm^2. From the test results, it can be concluded that the use of 1% admixture superplasticizer and 5% hydrated lime is the most optimal mixture compared to the others, with the compressive strength test result was 698.67 kg/cm^2. In addition, the author also found that the greater percentage of using the hydrated lime in the concrete mixture could reduce the compressive strength of the concrete.

ABSTRAK

Menurut SNI03-6468-2000, beton mutu tinggi meupakan beton yang mempunyai kuat tekan minimal sama dengan 41,4 MPa. Beton mutu tinggi ini bermanfaat pada beton pracetak dan pratekan. Penelitian ini bertujuan untuk menemukan bagaimana pengaruh penggunaan *admixture superplasticizer* dan kapur padam terhadap kuat tekan beton mutu tinggi K-500 saat ditinjau pada umur 3, 7, 14, dan 28 hari. Dalam penelitian ini, dibuat beberapa persentase penggunaan *admixture superplasticizer* terhadap campuran beton mutu tinggi, antara lain dengan proporsi 0 %, 1 %, 2 %, dan 3 %. Sedangkan untuk kapur padam yang diujicobakan, digunakan persentase sebesar 0 %, 5 %, 15 %, dan 25 %. Hasil pengujian kuat tekan beton K–500 tanpa *admixture superplasticizer* dan kapur padam berturut-turut diperoleh kuat tekan beton pada umur 3, 7, 14 dan 28 hari yaitu sebesar 208 kg/cm^2, 347 kg/cm^2, 462 kg/cm^2, dan 525 kg/cm^2 dan telah memenuhi syarat kuat tekan K-500. Penggunaan *admixture superplasticizer* 1 % sampai 3 % dengan kapur padam 5 % pada umur 28 hari diperoleh kuat tekan berturut-turut adalah 698,67 kg/cm^2, 668,89 kg/cm^2, dan 465,48 kg/cm^2. Kemudian penggunaan *admixture superplasticizer* 1 % sampai 3 % dengan kapur padam 15 % pada umur 28 hari diperoleh kuat tekan berturut-turut 508,89 kg/cm^2, 473,33 kg/cm^2, dan 359,70 kg/cm^2. Selanjutnya penggunaan *admixture superplasticizer* 1 % sampai 3 % dengan kapur padam 25 % pada umur 28 hari diperoleh kuat tekan berturut-turut: 320,00 kg/cm^2, 300,44 kg/cm^2, dan 254,22 kg/cm^2. Dari hasil pengujian beton pada umur 3, 7, 14 dan 28 hari, maka dapat dissimpulkan bahwa penggunaan 1 % *admixture superplasticizer* dan 5% kapur padam merupakan campuran yang paling optimal dibanding yang lain, dengan kuat tekan sebesar 698,67 kg/cm^2. Selain itu, dapat disimpulkan pula bahwa persentase penggunaan kapur padam yang semakin besar pada campuran beton dapat memperkecil kuat tekan beton.

Available online at http://dx.doi.org/10.36055/tjst.v19i1.16446

1. Introduction

According to SNI 03-6468-2000, high-strength concrete is concrete with a minimum compressive strength of 41.4 MPa. This type of concrete is useful in precast and prestressed concrete [1]. Although it has weakness such as the brittleness, the use of high-strength concrete in high-rise buildings is still highly profitable due to the slim dimensions compared to normal concrete. Therefore, using high-strength concrete can reduce the dead load of the building. This weakness can be overcome by the addition of reinforcing steel. Hence, the current concrete construction in Indonesia has progressed rapidly and made the demand for concrete construction materials increase.

In the production process, high-strength concrete requires optimization of three aspects that affect the strength of concrete, such as cement paste, aggregate, and cement-aggregate bond. The optimization of these three aspects should be started by paying attention to the production process, such as material selection, mix design, and quality control of the implementation.

Adding superplasticizer admixture and hydrated lime into concrete is a method that might increase the strength of concrete. Indeed, this addition should meet the requirements and be guided by the Indonesian government regulations regarding reinforced concrete. Based on this background, this study aimed to examine the effect of using superplasticizer admixture and hydrated lime in the manufacture of high-strength concrete K-500 when reviewed at the age of 3, 7, 14, and 28 days.

In this study, there were several variants of the proportion of superplasticizer admixture used for high-strength concrete mixtures, including 0%, 1%, 2%, and 3%. As for the hydrated lime that was tested, the percentages of 0%, 5%, 15%, and 25% were used. This study expected to be useful as a reference for determining how much hydrated lime material could be added in the manufacture of high-strength concrete, especially the K-500 concrete.

1.1. Aggregate

Aggregate is the main component of the road pavement structure, which is 90-95% aggregate by weight percentage, or 75-85% aggregate by volume percentage. Thus, the quality of the road pavement is also determined by the characteristic of the aggregate and the result of aggregate and other materials mixture [2]. The quality of aggregate give a high impact to the quality of concrete, given that aggregate occupies 70% to 75% of the total volume of concrete [3]. The used of good aggregate will generate a stronger, durable, and economical concrete. The effect of aggregate properties on concrete can be seen in table 1.

Table 1. Aggregate Properties on Concrete

Aggregate Properties	Effects on	Concrete Properties
Shape, texture, gradation	Liquid concrete	Workability, setting time, hardening
Physical properties, chemical properties, mineral	Hardened concrete	Strength, hardness, durability

1.2. Classification of Aggregate

Coarse aggregate is the aggregate retained by sieve no. 8 (2.36 mm) [4], while fine aggregate is an aggregate that passes sieve no. 8 (2.36 mm). The mineral filler is the fraction of the fine aggregate that passes the sieve no. 200 (0.0075 mm) minimum of 75% of the total weight of aggregate. While the mineral ash is the fraction of fine aggregate that 100% passes the sieve no. 200 (0.0075 mm) [5].

Mineral filler and mineral ash can occur naturally or through a crushing plant process. These minerals are the necessary ingredients to make the mixture becomes denser, more durable, and waterproof. Besides, the properties of the mixture could change due to the amount or the properties of these minerals. A slight excess or deficiency of these minerals will cause a too wet or too dry mixture. Therefore, the type and amount of the mineral used in the mixture must be controlled carefully. In the next section, the following aggregates are classified according to their weight, shape and surface texture.

- Based on weight

  Based on weight, aggregates are classfied into three type namely normal aggregate, light aggregate, and heavy aggregate. The normal aggregate is produced from the crushing plant or quarry method (mining directly from natural sources such as granite, basalt, quartz, etc). The average weight is 2.5 – 2.7 or not less than 1.2 kg/dm3. Concrete made by normal aggregate is normal concrete with a density of 2,200 to 2,500 kg/m3 [6].To build a building that takes its self-weight into account, people use lightweight concrete made by lightweight aggregate. This aggregate is mostly used for pre-cast concrete. Concrete made with lightweight aggregates has good fire resistance. Heavy aggregates have a minimum specific gravity of 2,800 kg/m3. For examples, the magnetic (Fe_3O_4), barytes ($BaSO_4$), and iron filings. The concrete used with this aggregate is usually used as a shield from X-ray radiation.

- Based on shape

  There are five types of aggregate when classified based on their shape, namely rounded, irregular, angular, and flaky. The rounded shape aggregates are fully spherical or egg-shaped, for example sand and gravel from rivers and beaches. The irregular aggregate is the natural shape due to friction and has rounded sides or edges, such as river pebbles and the land pebbles from volcanic lava. The angular shape is irregular, has sharp corners and a rough surface, such as crushed stone. Finally, the flaky aggregate has a flat shape with a thickness that is much smaller than its length and width. Usually, the thickness is less than one-third of the width. This type of aggregate comes from layered stones.

- Based on texture of the surface

  According to the texture of the surface, aggregates are classified into two types, the smooth and rough surface aggregate. The smooth surface aggregate need less water than the rough one. From a research outcome, a rougher texture of aggregate’s surface could increase the friction between the cement paste and the surface of the aggregate. Therefore, the concrete that used rough surface aggregate tends to be a poor quality concrete.

1.3. Concrete

Herawati (2006) said, “Concrete is a mixture consist of nature aggreate, such as gravel, sand, crushed stone, with Portland cement as a binder, then the Portland cement and water forms a paste that binds the aggregate grains into a solid mass that is insoluble in water.” [6]

The mixture of concrete components is made until homogenous with a specific ratio and produces a plastic state for easy processing. Furthermore, if necessary, the additional materials or admixture can be added.

The hydration heat produced in the chemical reaction of cement and water generates the bonds of the aggregates' granules. Both the rough and smooth surface aggregate reacts with the cement and water to produce a hardening and increase the strength of the concrete. The strength of the concrete continuously increases until it reaches the maximum strength at the age of ± 28 days.

After hardening, the concrete can withstand the compression until it reaches the desired maximum compression. However, the concrete is not able to withstand the tension. Therefore, reinforcement is needed to withstand the tension. This kind of concrete is called reinforced concrete.

Still, there are also other types of concrete, such as pre-compressed concrete and composite concrete. Pre-stressed concrete is a form of concrete where initial compression is given in the concrete before applying the external load so that stress from external loads is counteracted in the desired way during the service period. Composite concrete is a compound of concrete with other materials such as steel and is used to withstand compression [6].

1.4. The Properties of Concrete

- Fresh concrete

  Fresh concrete is a mixture of water, cement, and aggregate in a plastic state (before cement binds) and can be added by additional materials when needed [6]. Several things can affect the workability of fresh concrete, such as environmental conditions, time, and stability.

  Environmental factors that deteriorate the workability of concrete are temperature, humidity, and wind flow speed. Temperature affects the amount of water used because the increase in temperature accelerates the amount of water used due to evaporation. Meanwhile, humidity and wind speed affect the rate of evaporation of water.

  The deterioration of the workability of concrete concerning time is a direct result of loss of water, adsorption of aggregates, and initial hydration of cement. Furthermore, from a stability point of view, the fresh concrete mixture must be stable and evenly distributed during mixing until the solidification is complete before the concrete binds. The differences in grain size and specific gravity of the concrete mixture ingredients result in the tendency of these materials to be separated or hard to mix.
- Hardened Concrete

  The properties of fresh concrete are substantial within a few hours after the concrete is mixed. Meanwhile, the properties of hardened concrete are necessary to identify the utilization. The properties of hardened concrete includes compressive strength, tensile strength, durability, and wear time.

  Compressive strength is the most important thing because the quality of concrete is assessed based on this compressive strength. The strength of this concrete is expressed by the maximum load that it can carry because the other properties will improve in line with the increase in the strength of the concrete. There are two types of tensile tests for concrete, namely the Brazilian tensile test to obtain the split tensile strength of concrete and the direct tensile test to obtain the direct tensile strength of concrete.[6]

  Besides the strength of the concrete, it is also necessary to pay attention to the durability of the concrete used for construction. To produce durable concrete, people should mix the materials in a suitable ratio to produce homogeneous and easily compacted concrete.

  The concrete usually wears off by the fast airflow, resulting in abrasion of the concrete surface and causing holes in the concrete. The resistance of concrete to erosion and abrasion will increase in line with the increase in the strength of the existing concrete.

1.5. Age and Concrete Strength

The compressive strength will increase along with the increasing age of concrete. Usually, the compressive strength is measured when the concrete reaches the age of 28 days [7]. Prawito said that *"The strength of concrete will increase rapidly (linearly) until the age of 28 days, but after that, the increase is not too significant"* [8]. Generally, the concrete reaches 70% of the 28-day compressive strength in 7 days and will be 85%-90% in 14 days. The estimated compressive strength of each test object against the 28-day concrete can be seen in following Table 2.

Table 2. Conversion Factor for the Compressive Strength of 28-days Concrete

Age of Concrete	Ordinary Portland Cement	High-Performance Portland Cement
3-days	0.40	0.55
7-days	0.65	0.75
14-days	0.88	0.90
21-days	0.95	0.95
28-days	1.00	1.00
90-days	1.20	1.15
365-days	1.35	1.20

1.6. The Hydrated Lime on Concrete Mixture

Heins in Mulyono (2005) said that to made lime, the limestone containing silica and clay should be heated until it becomes clinker [9]. The heating process is carried out in a shaft furnace or rotary kiln with 800 to 1200 degrees celcius of temperature. The clinkers contain enough lime and silicates to produce quicklime. After getting in contact with the water, the unburnt lime produces hydrated lime.

Quicklime is produced from crushed limestone that releases carbon dioxide and leaving calcium oxide after the combustion process with the following chemical reaction: $CaCO3(s) \rightarrow CaO(s) + CO2(g)$. Meanwhile, the hydrated lime, also known as Calcium Hydroxide is a product of chemical reaction of the quicklime and water. The reaction is: $CaO(S) + H2O(l) \rightarrow Ca(OH)2(aq) + heat$.

2. Experimental Section

2.1. Study Area

This study was conducted in Civil Engineering Labroratorium of Sriwijaya State Polytechnic. This school is located in Palembang, Sumatera Selatan. Coarse aggregates are taken from Baturaja area and fine aggregates were originally from Tanjung Raja area. Some tests on these materials were conducted before finding the effect of using superplasticizer and hydrated lime on the compressive strength of high-strength concrete K-500 when reviewed at the age of 3, 7, 14, and 28 days.

2.2. Methods

- The Quality Checks on Materials

  The quality checks on materials tested in this study included 2 kilograms of coarse aggregate, fine aggregate, and cement Portland. The test on aggregates includes the sieve analysis, specific gravity, water absorption test, and the moisture content test. Meanwhile, only the test to determine the specific gravity was carried out for the cement portland. The data obtained from these tests referred to the Indonesian National Standard (SNI)[4,5,10], the American Society for Testing Material (ASTM) [11], and the American Association of State Highway and Transportation (AASHTO)[12].
- The Effect of Using Superplasticizer and Hydrated Limed on Compressive Strengthof K-500 Conrcete

  When the quality of the material has met the standards, 120 pcs of concrete cube specimens were made to test the compressive strength of concrete. The outcomes were then evaluated and compared to the compressive strength of high-strength concrete made without using admixture and hydrated lime. Several percentages of superplasticizer for high-strength concrete mixtures were used, such as the proportions of 1%, 2%, and 3%. As for the hydrated lime that was tested, the percentages were 5%, 15% and 25%. The outcomes of the compressive strength test for each variations will be analyzed following Indonesian National Standard (SNI) [13,14] then it will be made into some tables and curves in the results section below.

3. Results and Discussion

3.1. The Quality Checks on Materials

3.1.1. Sieve Analysis

Ten type of sieves were used to test the coarse and fine aggregates. The results for sieve analysis of coarse aggregate is shown in Table 4 and the grading curve of coarse aggregate is shown in Figure 1 below.

Table 3. Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	Weight Retained		Cummulative Percent (%)	
	Gram	%	Retained	Passed
38	0	0	0	100
19	1278.9	63.94	63.95	36.05
9.5	709.4	35.48	99.42	0.57
4.8	8.1	0.41	99.83	0.17
2.4	3.30	0.17	100	0
1.2	0	0	100	0
0.6			100	0
0.3			100	0
0.15			100	0
0.075			100	0
PAN			100	0
Total	2000	100	963.19	

Finess Modulus : Sum of Cummulative Percent Retained/100

Finess Modulus : 963.19/100 = **9.63**

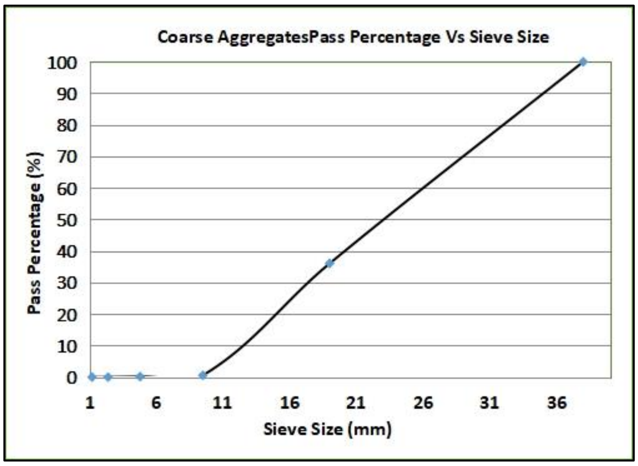

Figure 1. Grading Curve for Coarse Aggregate

The result of sieve analysis exhibit the finess modulus of coarse aggregate is 9.63. Meanwhile, the results for sieve analysis of fine aggregate is shown in Table 5 and the grading curve of fine aggregate is shown in Figure 2 below.

Table 4. Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Weight Retained		Cummulative Percent (%)	
	Gram	%	Retained	Passed
9.5	0	0	0	100
4.8	8.1	0.81	0.81	
2.4	21.4	2.14	2.95	
1.2	86.2	8.62	11.57	
0.6	204.3	20.43	32	
0.3	541	54.1	86.1	
0.15	114.4	11.44	97.54	
0.075	18.9	1.89	9943	
PAN	5.7	0.57	100	
Total	2000	100	430.4	
Finess Modulus :		Sum of Cummulative Percent Retained/100		
Finess Modulus :		430.4/100 = **4.30**		

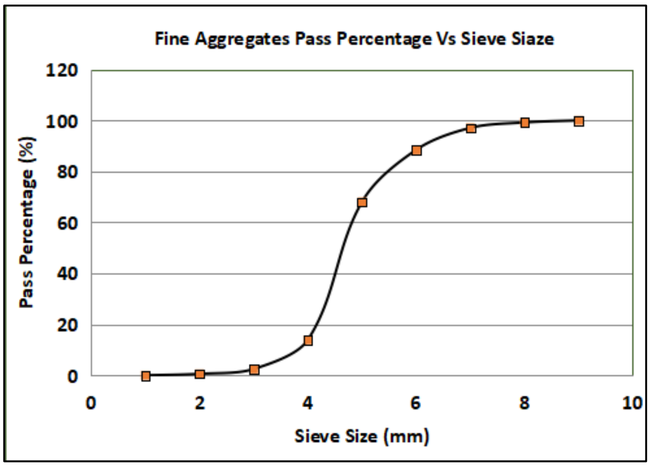

Figure 2. Grading Curve for Fine Aggregate

The result of sieve analysis exhibit the finess modulus of fine aggregate is 4.30 and the fine aggregate gradation is in zone 2. It means the grain size of sand is ideal.

3.1.2. Specific Gravity and Water Absorption Test

In mix design, knowing the proportion of the aggregates that have to be put in a mixture is substantial. Therefore, it is necessary to conduct the test for specific gravity and water absorption. The results of the specific gravity and water absorption of coarse aggregate and fine aggregate can be seen respectively in Table 5.

Table 5. The Specific Gravity and Water Absorption of Coarse Aggregate

Code	Description	Coarse Aggregate	Fine Aggregate
A	Weight of SSD sample	498.9 g	500 g
B	Weight of oven dried sample	482.3 g	488 g
C	Weight of Pycnometer with water	1295.3 g	1230 g
D	Weight of Pycnometer with water and sample	1590.7 g	1418 g
B / (C+A-D)	Bulk specific gravity	**2.370**	**2.302**
A / (C + A – B)	Bulk SSD specific gravity	**2.451**	**2.358**
(A-B) / B * 100%	Water absorption	**3.44 %**	**2.46 %**

The specific gravity of coarse aggregate ranges from **2.0 to 2.6.** The greater the specific gravity of the aggregate, the better the concrete produced. After computing the ratio of its mass in air to its bulk volume, the results exhibit that the bulk specific gravity of coarse aggregate is **2.370** and the bulk specific gravity fine aggregate is **2.302**. These results indicate that the aggregates used in this study are proper to produce a good concrete.

3.1.3. Moisture Content

Aggregates are porous and can absorb moisture to some extent. When using Portland Cement Concrete (PCC), the aggregate moisture content will affect the water content and thus the water-cement ratio also. Therefore, it is necessary to test the moisture content of the aggregate. Table 6 exhibit the result of moisture content test of the coarse and fine aggregate.

Table 6. Moisture Content of Aggregates

Code	Description	Coarse Aggregate	Fine Aggregate
(W1)	Weight of SSD sample	692.8 g	836.2 g
(W2)	Weight of oven dried sample	1692.8 g	1836.2 g
(W3)	Weight of Pycnometer with water	1000 g	1000 g
(W4)	Weight of Pycnometer with water and sample	1660.4 g	1742.40 g
(W5)	Bulk specific gravity	591.8 g	906.2 g
Moisture content	(W3-W5)/W5 *100 %	**3.348 %**	**10.35 %**

3.1.4. Impact Value of Coarse Aggregate

The purpose of the impact test is to determine the toughness of coarse aggregate against loading. The results of aggregate impact value test are shown in Table 7.

Table 7. Impact Value of Coarse Aggregate

Code	Description	Weight 1	Weight 2
(W1)	Weight of container and dry sample taken (fraction passing through #12.5 mm sieve and retained #10 mm sieve)	758.8 g	759.6 g
(W2)	Weight of container	408 g	408 g
(W3)	Weight of dry sample	350.8 g	351.6 g
(W4)	Weight of sample after the impact and passing through #2.36mm sieve	40 g	39.34 g
(Wb)	Aggregate impact value	11,40 %	11,18%
	Average aggregate impact value	**11.29%**	

Specified limits of percent aggregate impact value for cement concrete is 30%. In this study, the coarse aggregate impact value is 11.29%, thus this material has met the standard for cement concrete.

3.1.5. Specific Gravity of Portland Cement

The calculation for specific gravity of portland cement is exhibited in Table 8.

Table 8. Specific Gravity of Portland Cement

Code	Description	Calculation
(W1)	Weight of sample	64.00 g

Code	Description	Calculation
(V1)	Weight of container with sample	0.91 g
(V2)	Weight of sample in stockpile condition	21.21 g
(V2-V1)	Weight of container with oven-dried sample	20.30 g
(d)	Specific gravity of 4ºC water	1.00
W1 / (V2-V1) * d	Specific gravity of cement	**3.15**

The specification of specific gravity of portland cement is between range 3.0 to 3.20. The test result shows that the specific gravity of portland cement used in this study is 3.15 and has met the specification.

3.2. The Effect of Using Superplasticizer and Hydrated Limed on Compressive Strength of K-500 Concrete

As a comparison, before testing the compressive strength of K-500 concrete with admixture superplasticizer and hydrated lime, the compressive test for concrete without any admixture was conducted. The result is shown in Figure 3.

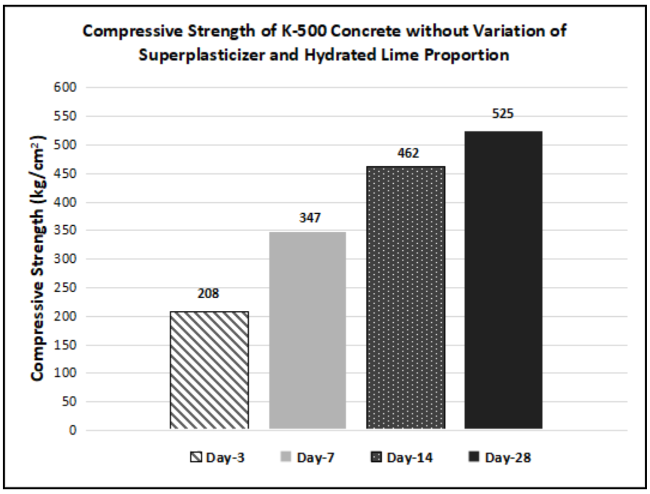

Figure 3. Compressive Strength of K-500 Concrete without Variation Of Superplasticizer and Hydrated Lime

The results of the compressive strength test of K-500 concrete without superplasticizer and hydrated lime at the age of 3, 7, 14 and 28 days respectively were 208 kg/cm^2, 347 kg/cm^2, 462 kg/cm^2, and 525 kg/cm^2. This results has met the requirements for compressive strength of K-500.

Forward, the result of the compressive strength test of K-500 concrete with variation of superplasticizer and hydrated lime proportion is exhibited in Figure 4 below.

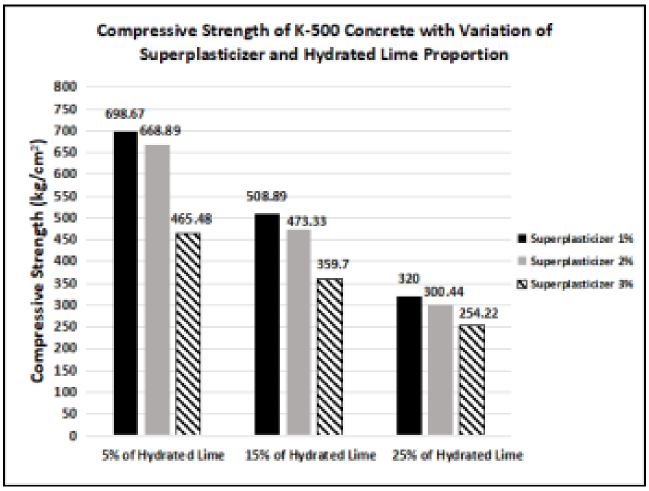

Figure 4. Compressive Strength of K-500 Concrete with Variation of Superplasticizer and Hydrated Lime

As shown in the Figure 4, when using 1% to 3% superplasticizer with 5% of hydrated lime at the age of 28 days, the compressive strength obtained are 698.67 kg/cm^2, 668.89 kg/cm^2, and 465.48 kg/cm^2. The compressive strength of using 1% to 3% of superplasticizer with 15% of hydrated lime at the age of 28 days are 508.89 kg/cm^2, 473.33 kg/cm^2, and 359.70 kg/cm^2. As for the compressive strength of using 1% to 3% superplasticizer with 25% of hydrated lime at the age of 28 days are 320.00 kg/cm^2, 300.44 kg/cm^2, and 254.22 kg/cm^2.

These results indicate that from three variations of using hydrated lime, the highest compressive strength of the concrete mixture is always obtained when 1% of superplasticizer is included. The highest compressive strength designed is 698.67 kg/cm^2 when 1% of superplasticizer and 5% of hydrated lime is used. It means the compressive strength of the concrete mixture designed has surpassed the K-500 concrete without any admixture.

4. Conclusion

The more use of the percentage of hydrated lime in the concrete mixture with the variation of superplasticizer resulted in a decrease trend in compressive strength of the concrete. The use of 1% to 3% admixture superplasticizer with 5% of hydrated lime at the age of 28 days obtained compressive strength successively 698.67 kg/cm^2, 668.89 kg/cm^2, and 465.48 kg/cm^2. With the additional of hydrated lime of 15% the compressive strength decreased to 508.89 kg/cm^2, 473.33 kg/cm^2, 359.70 kg/cm^2 then adding 25% of hydrated lime in the mixture given the lowest value of 320.00 kg/cm^2, 300.44 kg/cm^2, and 254.22 kg/cm^2 respectively. However, the result of compressive strength of the concrete mixed with 1% and 2% of superplasticizer with 5% of hydrated lime have exceeded the compressive strength of the design concrete with the value of 698.67 kg/cm^2, 668.89 kg/cm^2 compared to 525 kg/cm^2. The results depicted that the hydrated lime cannot provide additional strength to the concrete especially with the addition of 15% and 25% of hydrated lime.

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