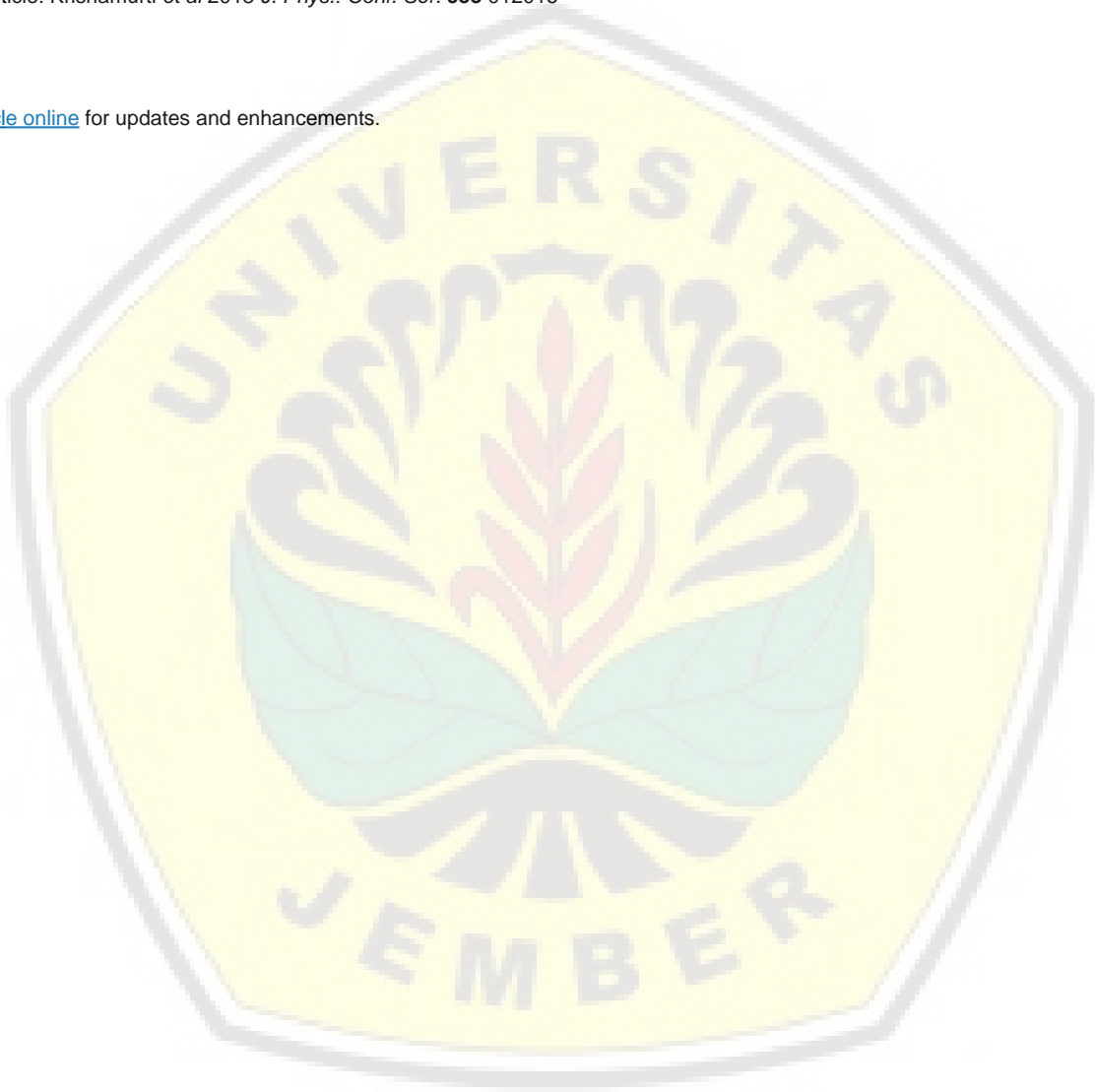**PAPER • OPEN ACCESS**

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Development of Mix Design Method in Efforts to Increase Concrete Performance Using Portland Pozzolana Cement (PPC)

Krisnamurti[1,2], A Soehardjono[2], A Zacoeb[2] and A Wibowo[2]

[1]Department of Civil Engineering, Faculty of Engineering, University of Jember, Jember 68121, Indonesia.
[2]Department of Civil Engineering, Faculty of Engineering, University of Brawijaya, Malang 65145, Indonesia

E-mail: murti_krisna.teknik@unej.ac.id

Abstract. Earthquake disaster can cause infrastructure damage. Prevention of human casualties from disasters should do. Prevention efforts can do through improving the mechanical performance of building materials. To achieve high-performance concrete (HPC), usually used Ordinary Portland Cement (OPC). However, the most widely circulating cement types today are Portland Pozzolana Cement (PPC) or Portland Composite Cement (PCC). Therefore, the proportion of materials used in the HPC mix design needs to adjust to achieve the expected performance. This study aims to develop a concrete mix design method using PPC to fulfil the criteria of HPC. The study refers to the code/regulation of concrete mixtures that use OPC based on the results of laboratory testing. This research uses PPC material, gravel from Malang area, Lumajang sand, water, silica fume and superplasticizer of a polycarboxylate copolymer. The analyzed information includes the investigation results of aggregate properties, concrete mixed composition, water-binder ratio variation, specimen dimension, compressive strength and elasticity modulus of the specimen. The test results show that the concrete compressive strength achieves value between 25 MPa to 55 MPa. The mix design method that has developed can simplify the process of concrete mix design using PPC to achieve the certain desired performance of concrete.

1. Introduction

The collapse of bridges, high-rise buildings and other infrastructure caused by earthquakes is a disaster that must be prevented or minimized its impact on the number of casualties. Prevention of disasters in civil engineering can be done by improving the mechanics' performance of building materials. Research to improve the performance of concrete mechanics continues to be implemented in the construction world. The mix design of concrete is a reminiscent topic of concrete materials science, various kinds of the concrete mix design methods are put forward in the past century. Concrete proportions must be selected to provide the necessary flexibility, density, strength, and durability for the application. In addition, when the mass concrete is being proportioned, consideration must be given to the generation of heat [1].

The maximum bulk density theory of high-performance concrete was a method to design concrete without utilizing coarse aggregate and with a large amount of cement. The mixing proportion method based on aggregate gradation optimization and phase volume analysis was a method to design concrete

which is used coarse aggregates and it has less cementitious materials content [2]. A packing density theory is a method of concrete mix design which has been successfully used in self-compacting concrete by determining the optimum mortar to aggregates packing voids ratio. The main steps to attain the concrete mix design in this method are: a) minimizing the voids volumes related to the coarse aggregate, b) minimizing the water-binder ratio, c) maximizing the density of the cementitious materials and d) optimizing the flowability and requirements of the fresh concrete [3]. Particle Packing Method (PPM) is a mix design approach method to obtain maximum possible packing density using a mixture of coarse and fine aggregates. This is a process of optimization where the smaller particles are used to fill up the voids between large particles. The size (coarse or fine), shape (rounded or angular) and type of parent rock of the aggregate has a significant effect on the performance of concrete. The packing characteristics of a single size of aggregates and its influence on the packing of the mixture of aggregates are the basis of this method. The increase in packing density leads to the minimization of voids and hence, the requirement of binder and water can be reduced. Two steps in the PPM mix design are a) Determination of aggregate fractions and packing density and b) Determination of paste content [4]. Another method is based on the relations between slump flow, coarse aggregate average diameter and volume of coarse aggregate used in self-compacting concrete, it was found that the preferable slump flow was that coarse aggregate could flow into a compact single layer status when the slump flow test was taken [5].

ACI 211–1 offers a comprehensive procedure for proportioning normal weight concrete of a maximum specified compressive strength of 40 MPa. The obtained mixture components do not include any supplementary cementitious materials or admixtures, except for an air-entraining admixture. This procedure is applicable to aggregate with a wide range of mineralogical and granulometric properties. It essentially assumes that the w/b ratio and the amount of entrained air are the only parameters affecting strength, and that concrete slump is affected by the maximum size of the coarse aggregate, the amount of mixing water and the presence or absence of entrained air. Where a set of proper values for the water/cement ratio and the amount of mixing water has been selected, the so-called absolute volume method is applied to calculate the mix proportions, i.e. the proportions of the mass of the different ingredients are transformed into volume proportions. Data that are needed to apply the ACI 211–1 procedure includes the fineness modulus of the fine aggregate, the dry-rodded unit weight of the coarse aggregate, the specific gravity of the aggregates, which are determined in the laboratory, and the free moisture and absorption capacity of the aggregate. This procedure assumes that the aggregate is well graded. The strength of hydrated cement paste can be improved by paying close attention to the parameters: porosity, grain size, and inhomogeneities [6]. According to Abram's law for strength development, the strength of workable concrete mix is dependent only on the water-binder ratio. Lesser the water-binder ratio in a workable mix greater will be its strength [7]. With given concrete materials and conditions of test the quantity of mixing water used determines the strength of concrete [8].

Each component of the concrete material has a very significant effect on the mechanical performance of the concrete. The accuracy of the examination results of the properties of a concrete material component is crucial in preparing the mixed plan to improve the performance of the concrete. The majority research which has been done in improving the performance of concrete using Type I Portland Cement. This type is often described by the term "Ordinary Portland Cement", or OPC. In fact, Type I Portland cement is no longer available in the market. The most widely circulating cement types today are Portland Pozzolana Cement (PPC) or Portland Composite Cement (PCC). It is, therefore, necessary to adjust the proportion of the material used in the concrete mixed design process to achieve the desired performance.

The specific gravity of the cement is assumed to be 3.15. The specific gravity of blended cement (PPC or PCC) will be less than that of Portland cement. Thus, when using either blended cement or supplementary cementitious materials, the yield of the concrete mixture should be adjusted using the actual specific gravities of the materials used [1]. The concrete mix produced with PPC possesses nearly same quality as of Type I Portland Cement, except with adjustments in the water-cement ratio as such the heat of hydration of PPC is lower than Type I Portland Cement, the cement content obtained is

slightly higher for blended cement [7]. Under certain circumstances, the service life of a reinforced concrete structure can double when PPC is used instead of Type I Portland Cement [9].

For usual concrete and for a class I high-performance concrete (compression strength between 50 MPa and 75 MPa), the strength gains are very significant when silica fume dosage increases from 5% to 10%, but any further addition of silica fume results in a much smaller strength increase. The specific gravity of silica fume is about 2.2, a usual value of vitreous silica. From a physical point of view, silica fume particles appear to be perfectly spherical, with diameters ranging from less than 0.1 μm to about 1 μm or 2 μm, so that the average silica fume sphere is 100 times smaller than an average cement particle. Because of their fineness, silica fume particles can fill the voids between the larger cement particles, when they are well deflocculated in the presence of an adequate dosage of superplasticizer. The filler effect is also said to be responsible for the increase in the fluidity of concretes with a very low water/binder ratio [6].

Since different aggregates, cement, and cementitious materials generally produce different strengths at the same water/cement or water/binder ratio, it is highly desirable to have or to develop the relationship between strength and the water-binder ratio (w/b) for the materials to be used. Differences in strength for a given water-binder ratio may result from changes in maximum size of aggregate; grading, surface texture, shape, strength, and stiffness of aggregate particles; differences in cement types and sources; air content; and the use of chemical admixtures that affect the cement hydration process or develop cementitious properties themselves. In view of their number and complexity, it should be obvious that accurate predictions of strength must be based on trial batches or experience with the materials to be used [1]. Workability, density and compressive strength at constant water-binder ratio increase with the increase in the coarse aggregate particle size and with curing age [10].

The mass of the mixing water added at the mixer is known, but the actual water present in the mixture is not, because the aggregates are not likely to be in their SSD state and the same water is 'hidden' in the liquid superplasticizer; therefore, the water/binder ratio of the mix is not known. Thus, it is necessary to calculate the water corrections to be able to know precisely the amount of water present in the mixture. This is done according to the very simple flowchart presented in Figure 1 [6].
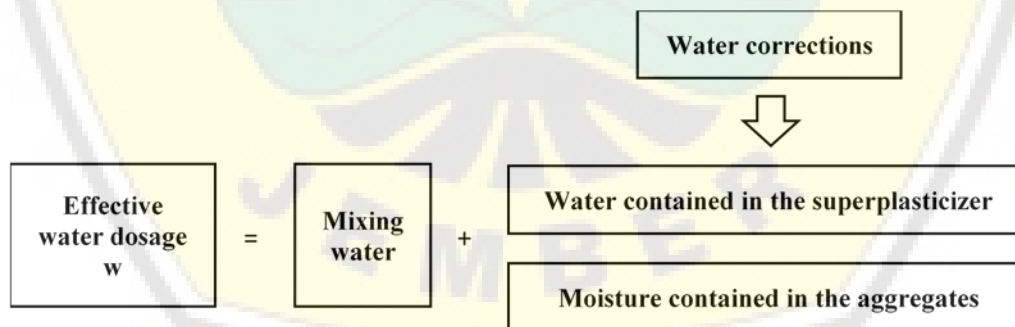

Figure 1. Calculation of the effective water dosage, w, of a trial batch [6]

This study aims to develop a concrete mixed design method to improve the mechanical performance of concrete using Portland Pozzolana Cement (PPC). The study was carried out about the code/regulation of concrete mixtures using Type I Portland Cement in the construction and validated fields based on experimental results in the laboratory.

2. Materials and methods

2.1. Materials properties

This research material uses Portland Pozzolana Cement, gravel from Malang area, Lumajang sand, silica fume and superplasticizer. The constituent materials were calculated by using the absolute volume method [11]. Silica fume has been used in high-performance concrete at a dosage rate of 10% of cement

weight. Since strength and other important concrete qualities such as durability, shrinkage, and cracking are related to the total water content and w/b ratio, water-reducing admixtures are used to improve concrete quality. This research is using polycarboxylate copolymers Sika® ViscoCrete®-3115 N which facilitates extreme water reduction, excellent flowability with optimal cohesion and strong self-compacting behaviour. Sika® ViscoCrete®-3115 N is used for the types of concrete: High flow concrete, Self-compacting concrete (SCC), Concrete with very high-water reduction (up to 30%), High strength concrete, Watertight concrete, and Pre-cast concrete.

Some properties of aggregate are tested, which include saturated surface dry condition (SSD test), fineness modulus, humidity, water absorption, specific gravity, a finer material less than a 75-μm, and Los Angeles abrasion value test as shown in Figure 2 until Figure 5.

Figure 2. SSD test

Figure 3. Sieve analysis

Figure 4. Specific gravity test

Figure 5. Los Angeles abrasion test

2.2. Mix design method

In this mix design method, there are several definitions used in the calculation. The water content, w_{tot}, of an aggregate is defined as the amount of evaporable water divided by the dry mass of the aggregate and is expressed as a percentage. The amount of water absorbed in the aggregate when it is in the SSD state, w_{abs}, corresponds to the aggregate absorption. This absorption is expressed as a percentage of the mass of the dry aggregate. The difference between the total water content of an aggregate, w_{tot}, and its water content in the SSD state, w_{abs}, is called the moisture content of the aggregate and is denoted by w_h. The moisture content of an aggregate can be negative if the total water content is lower than the water absorption. This occurs frequently in summer for coarse aggregates. The specific gravity of an aggregate in the SSD state is called the SSD specific gravity.

The SSD specific gravity expresses how much denser than water an SSD aggregate is. The application of Archimedes' principle shows that G_{SSD} is the specific gravity that must be used to calculate exactly the volume occupied by the aggregates in the concrete mix. For Portland Cement or any supplementary cementitious material, the specific gravity, G_c, is equal to the mass of the dry material divided by its dried density. The expression 'supplementary cementitious material content' is defined as the amount of supplementary cementitious material and/or filler used when making a high-performance

concrete as a percentage of the cement mass. Therefore, it is always better to give the superplasticizer dosage as a number of solids it contains expressed as a percentage of the mass of cement. To pass from a dosage expressed in litres per cubic meter to a dosage expressed in solids, it is necessary to know the value of the specific gravity of the liquid superplasticizer and its solids content [6].

Determination of concrete mixed design is done by the absolute volume method. Variations were made to the water/binder ratio and the calculations were adjusted to the aggregate water content as well as the saturation point factor of the superplasticizer used. By using mix design sheet which has been prepared by Aitcin based on ACI 211-1 [6]. The concrete mixed design is obtained with the change of w/b value from 0.32 to 0.26 as shown in Table 1.

Table 1. Composition of concrete mix design

		Mix 1	Mix 2	Mix 3	Mix 4
w/b ratio		0.32	0.30	0.28	0.26
Water	(litres)	121.54	121.76	122.02	122.32
Cement	(kg)	393.75	420.00	450.00	484.62
Silica fume	(kg)	43.75	46.67	50.00	53.85
Gravel	(kg)	1,066.80	1,066.80	1,066.80	1,066.80
Sand	(kg)	825.77	798.47	767.26	731.26
Superplasticizer	(litres)	9.04	9.64	10.33	11.13

Comparison of sand and gravel used in this study was 42%: 58%. This comparison is the result of calculations obtained from the mix design program used. In an examination of the combined zone with a maximum aggregate grain size of 19 mm, the limits of the provisions set for aggregate have been met as shown in the combination of aggregate zones of sieve analysis of aggregate combined with diameter 19 mm in Figure 6.
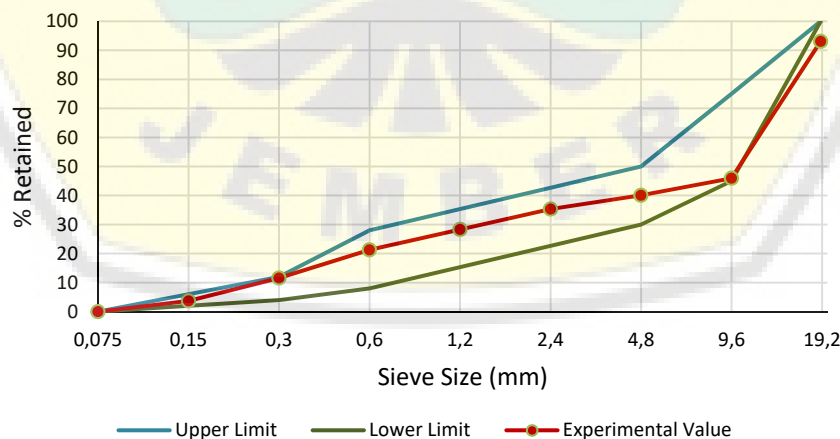

Figure 6. Aggregate zone with largest diameter 19 mm.

A mixer with a capacity of 120 L is used to mix concrete materials. Gravel, sand, and silica fume are mixed dry for 2 minutes. After that, the cement is added and mixing is continued for 2 minutes. The superplasticizer (SP) is mixed with water mixer and added gradually to the dry mixture and the mixing is continued for 3 minutes. The mixing results are further put into a mould of a cylinder with a diameter of 15 cm and height of 30 cm, cylinder with a diameter of 10 cm and height of 20 cm, and 15 cm x 15

cm x 15 cm cube as shown in Figure 7. The concrete specimens were immersed in water for 7 days as shown in Figure 8. The compressive strength test is performed when the specimen has reached the age of 28 days. In the test of a cylindrical specimen with a diameter of 15 cm and a height of 30 cm, the deformation changes also measured using extensometer equipment as shown in Figure 9c.

Figure 7. Mixing concrete   **Figure 8.** Curing concrete specimens

Figure 9. View of compression strength testing of concrete specimens. a) Cube 15 cm x 15 cm x 15 cm. b) Cylinder 10 cm x 15 cm. c) Cylinder 15 cm x 30 cm

3. Result and discussion

The test results of the aggregate properties shown in Table 2. The average compressive strength of concrete specimens with different ratio w/b from 0.32 to 0.26 can be seen in Figure 10.

TABLE 2.   Physical and mechanical properties of aggregate.

Properties of fine aggregate	Unit	Value
Finenes modulus	-`	2.67
Humidity	%	2.80
Water absorption	%	0.30
Specific gravity	-	2.70
Finer material less than a 75-µm	%	0.00
Properties of coarse aggregate		
Finenes modulus	-	7.05
Humidity	%	1.19
Water absorption	%	1.95
Specific gravity	-	2.69
Los Angeles abrasion value	%	18.65

The reduction of w/b ratio from 0.32 to 0.26 leads to an increase in average compressive strength of concrete specimens, from a compression test with a cylindrical specimen with a diameter of 15 cm and

a height of 30 cm, a cube of 15 cm x 15 cm x 15 cm, as well as from specimen-cylinder with diameter 10 cm and height 20 cm.
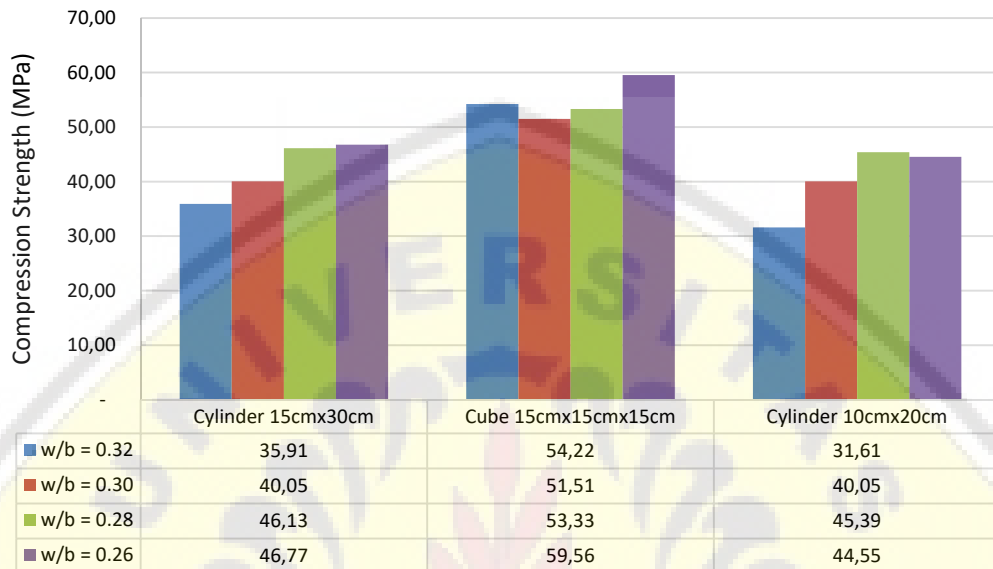

	Cylinder 15cmx30cm	Cube 15cmx15cmx15cm	Cylinder 10cmx20cm
w/b = 0.32	35,91	54,22	31,61
w/b = 0.30	40,05	51,51	40,05
w/b = 0.28	46,13	53,33	45,39
w/b = 0.26	46,77	59,56	44,55

Figure 10. Average compression strength of concrete specimens

From the test of the compressive strength of the cylindrical test specimen with a diameter of 15 cm and a height of 30 cm can be seen the relationship between compressive strength and elastic modulus of the specimen as shown in Figure 11. The increased compressive strength of concrete will also increase the modulus value of the elasticity of the concrete material.
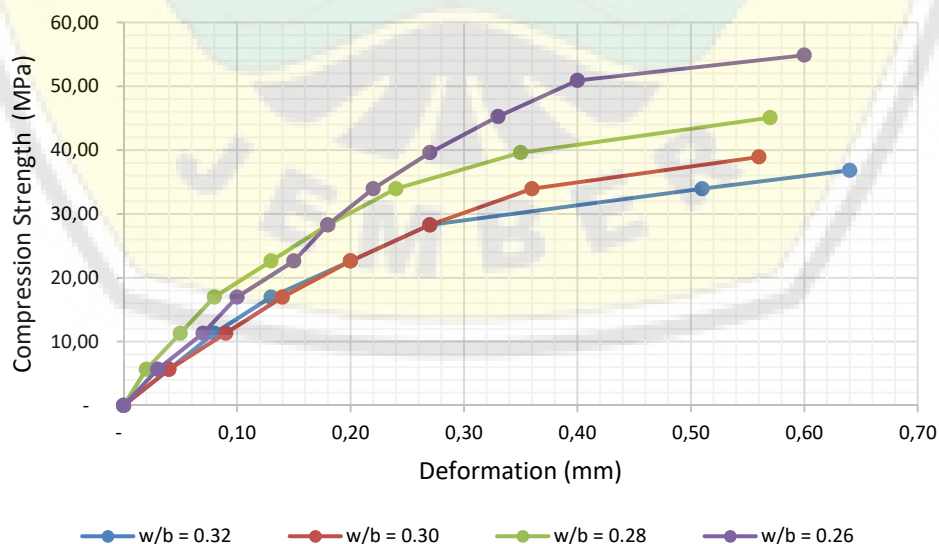

Figure 11. Compression strength and deformation relationship

The relationship between the compressive strength of concrete and the weight of the concrete specimens can be seen in Figure 12. The relationship can be described by the equation $y = 1E\text{-}08x^{8.4971}$. It is seen that the more weight of the specimen, the more likely it will be the compressive strength. But

of course, this will still be influenced also by the coarse aggregate strength as the constituent component of the concrete. Therefore, an aggregate strength test is required before being used in concrete mixing.
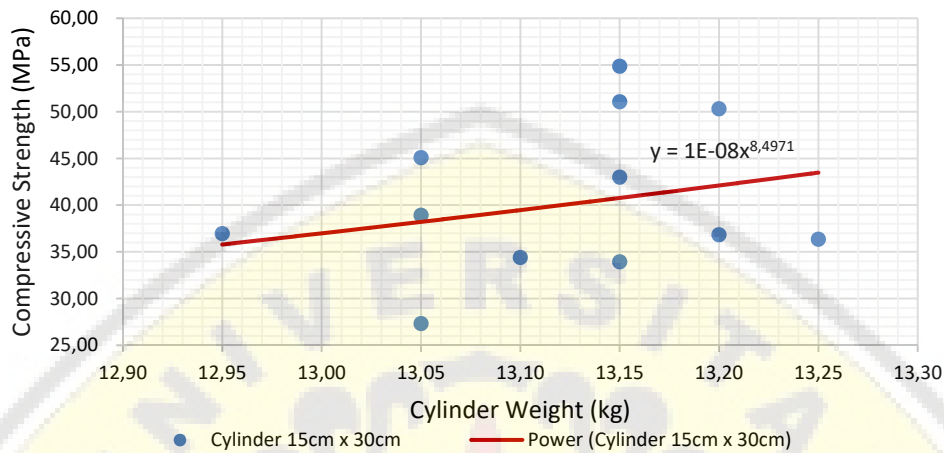

Figure 12. Cylinder weight and compressive strength relationship.

The relation between w/b ratio and compressive strength of concrete can be seen in Figure 13. The difference of shape and size of the specimen will produce a different value of compressive strength for the same w/b ratio. The relation between the w/b ratio with a compressive strength of 15 cm x 15 cm x 15 cm cubic specimens is $30.357x^{-0.473}$. The compressive strength values generated in this test of cubic specimen range from 50 MPa to 60 MPa. While the relation w/b ratio with compressive strength of 15 cm x 30 cm cylindrical test specimen is $y = 6.129x^{-1.512}$ and for 10 cm x 20 cm cylindrical test specimen is $y = 5.0478x^{-1.662}$. The compressive strength of cylindrical specimen obtained ranges from 25 MPa to 55 MPa. This relationship can be used to predict the compressive strength of concrete as one form of concrete performance produced by using PPC and coarse aggregate with a diameter of 19 mm and the value of w/b ratio selected.
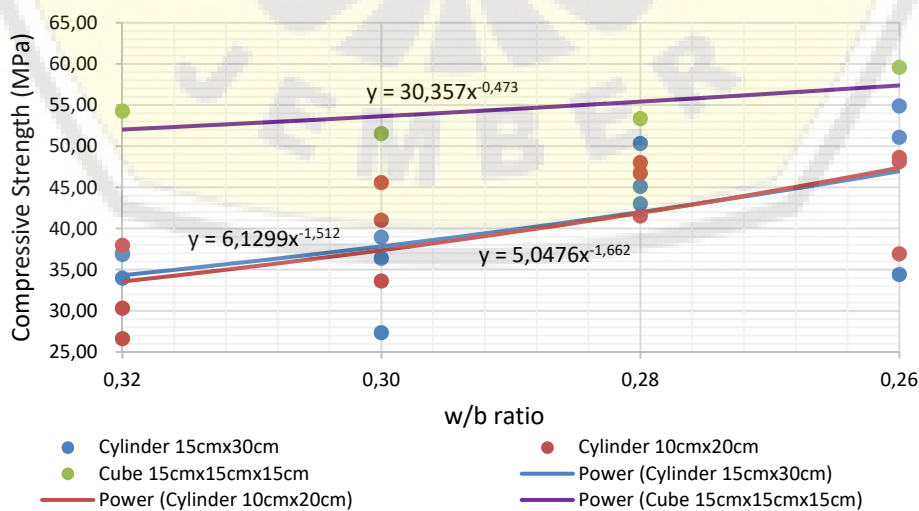

Figure 13. w/b ratio and compressive strength relationship.

4. Conclusion

From the results of this study, it can be concluded that the method of mix design that has been developed can simplify the process of planning a mixture of concrete, which using Portland Pozzolana Cement (PPC) to achieve the certain desired performance of concrete.

5. Acknowledgments

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