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A Comparative Study of Mechanical Properties Between Concrete Made By Using Portland Pozzolan Cement And Type I Portland Cement

KEYWORDS: pozzolan, Portland cement, compressive strength, modulus of elasticity, permeability

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ABSTRACT *The mechanical properties of concrete made by using Portland Pozzolan cement (PPC) have been compared to that made by using type I Portland cement (PCI) at the age of hydration 3, 7, 28 and 90 days. The compared mechanical properties concern compressive strength, modulus of elasticity and permeability. Concrete was made by using a proportion, by weight, of 1.0 cement: 2.0 sand: 3.0 crushed stone and water cement ratio of 0.4. The grain distribution of sand and crushed stone were designed according to SNI 03-2834-2000 to meet respectively the gradation zone 2 for fine aggregate and the granules with a maximum diameter of 40 mm for coarse aggregate. Tests were carried out using cylindrical specimens, diameter = 150 mm and height = 300 mm. The results show that at the early age, concrete using PPC produces lower compressive strength and modulus of elasticity but higher permeability coefficient compared to concrete using PCI. However, at the longer age (90 days), concrete using PPC can produce higher compressive strength and modulus of elasticity, respectively about 8% and 15%, and lower permeability coefficient, about 50%, compared to concrete using PCI. This phenomenon can be strongly attributed to the reduced porosity of concrete as indicated by the results of permeability test. The reaction result between reactive silica and alumina of Pozzolan in PPC with calcium hydroxide produced from the hydration of C3S and C2S in PCI contributes to increase the density of the concrete matrix such that, on the long period, the mechanical properties of concrete using PPC are better than that using PCI.*

INTRODUCTION

Concrete is a very popular building material used in the construction world. Many researches on concrete have already been realized and it will continue to answer the development of science and technology as well as environmental conditions. It is known that the strength of the concrete is strongly influenced by its constituent materials (water, cement and aggregates) so that the quality control of these materials must be considered carefully in order to obtain concrete as expected.

In concrete technology, Portland cement is the main component that serves as a hydraulic binder to bind and unify aggregate to become a solid mass. Various types of Portland cement have been developed in accordance with the type of building and environmental requirements. Type I Portland cement (PPI) is commonly used to make concrete. This type of cement is used for the buildings which do not require any special requirements [1]. With the development of technology and efforts to save costs production as well as to reduce environmental problems, it has been produced Portland Pozzolan cement (PPC), which is a mixture of Portland cement clinker with a material having properties of pozzolan [2].

Pozzolan is a mineral materials, mainly containing silica and alumina, which when grounded equivalent to granular cement and mixed with water at normal temperatures will react with lime to form a compound of calcium silicate hydrate C-S-H and calcium aluminate hydrates C-A-H, similar to the compound produced in the hydration process of cement [3, 4]. It is well known that the reaction of Portland cement major minerals i.e. C3S and C2S with water will produce C-S-H and free lime $Ca(OH)_2$. Free lime less contributes to the strength and even tends to disadvantage in terms of durability, when in the course of time it reacts with aggressive elements such as sulphate [3-5]. By blending Portland cement clinker and pozzolan, in certain proportions, it will obtain PPC having different character compared to PPI [3-5]. This different character will affect the mechanical properties of concrete made by using PPC.

This paper presents the results of a study which compare the mechanical properties between concrete made by using PPC and PCI at the age of 3, 7, 28 and 90 days. The compared mechanical properties include compressive strength, modulus of elasticity and permeability.

MATERIALS AND EXPERIMENTAL METHOD

Two type hydraulic binders used (PPC and PCI) originated from one of Portland cement industries in Indonesia. Natural sand and crushed stone were used as fine aggregate and coarse aggregate respectively. The grain distribution of sand and crushed stone were designed according to SNI 03-2834-2000 [6] to meet respectively the gradation zone 2 for fine aggregate and the granules with a maximum diameter of 40 mm for coarse aggregate. Some physical properties of PPC and PCI as well as the aggregates are presented in Table 1.

For each type of binder, concrete was made to produce cylindrical specimens with a diameter of 150 mm and a height of 300 mm. Concrete was made by using a proportion, by weight, of 1.0 cement: 2.0 sand: 3.0 crushed stone. The water cement ratio was 0.4.

TABLE - 1
PHYSICAL PROPERTIES OF PPC, PCI, SAND AND CRUSHED STONE

Materials	Unit weight (g/cm^3)	Specific gravity	Absorption (%)
PPC	1.19	-	-
PCI	1.25	-	-
Sand	1.58	2.56	3.63
Crushed Stone	1.52	2.40	2.74

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Compressive strength test was carried out by using a machine press Controls with capacity of 2000 kN while the permeability test was conducted by using Concrete Permeability Apparatus C530. The determination of the modulus of elasticity of concrete was done in accordance with ASTM C 469-94. Those tests were realized at 3, 7, 28 and 90 days. For each test it was used 3 cylindrical specimens.

RESULTS AND DISCUSSION

Compressive Strength

The results of the compressive strength test of concrete made by using PPC and PCI at the age of 3, 7, 28 and 90 days are shown in Figure 1. From this figure, it can be generally seen that the compressive strength of concrete increases with the increase of the hydration time. This happens on concrete made by using PPC and that made by using PCI.

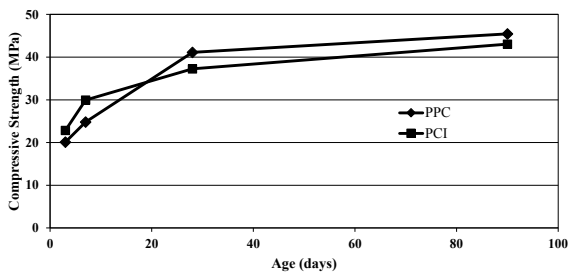

Figure 1 Compressive Strength of Concrete

However, it is also seen that the development of the compressive strength of concrete using PPC is relatively slower at early age compared to that using PCI. Up to the age of 7 days, concrete using PPC produces lower compressive strength, about 15%, compared to that using PCI. By the increase of the hydration time, especially after more than 20 days, concrete using PPC can produce higher compressive strength compared to concrete using PCI. Even, at the age of 28 and 90 days, concrete using PPC produces compressive strength respectively 41 and 46 MPa, which are higher respectively 10% and 8% compared to that using PCI. The development of compressive strength tends to continue after the age of 90 days.

Modulus of elasticity

The results of the modulus of elasticity test of concrete made by using PPC and PCI at various ages are shown in Figure 2. Relatively, the same phenomenon to the development of compressive strength can be seen from that figure, i.e. the modulus of elasticity increases with the increase of the age of hydration. This increase occurred in both concretes.

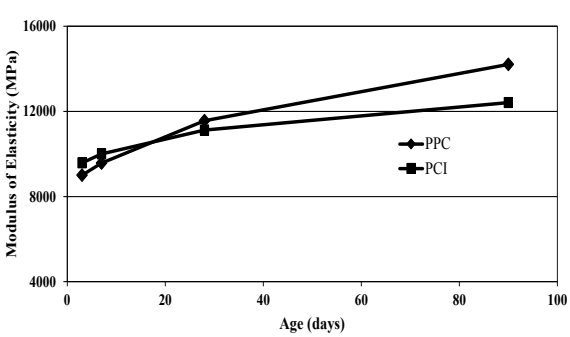

Figure 2 Modulus of Elasticity of Concrete

Figure 2 also shows that the development of the modulus of elasticity of concrete using PPC is relatively slower at early age compared to that using PCI. Up to the age of 7 days, the modulus of elasticity of concrete using PPC is only about 95% of that using PCI. By the increase of the hydration time, especially after more than 20 days, concrete using PPC can produce higher modulus of elasticity compared to that using PCI.

At the age of 28 and 90 days, concrete using PPC produces the modulus of elasticity respectively 11560 and 14212 MPa, which are higher, respectively 4% and 15%, than the concrete using PCI. It can be also seen that the development of the modulus of elasticity tends to continue after the age of 90 days.

Permeability

Figure 3 shows the results of permeability test of concrete made by using each type of binder at various ages. It can be seen that coefficient permeability of concrete, kp, decreases with the increase of the age of hydration. A sharp decrease of kp mainly occurs from age 3 to 7 days. This phenomenon occurs on both concretes.

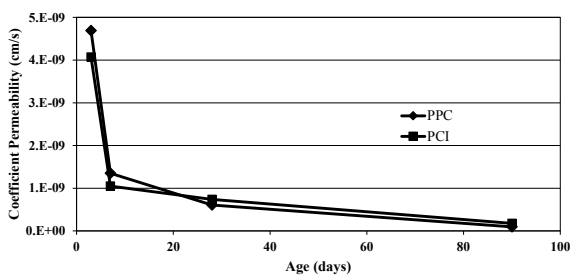

Figure 3 Coefficient of Permeability of Concrete

From Figure 3, it can be seen that at the early age kp of concrete using PPC is relatively higher than that using PCI. At the age of 7 days, kp of concrete using PPC is 30% higher than that using PCI. However, after the age of hydration is more than 20 days kp of concrete using PPC becomes lower than that of using PCI. When the hydration time reaches 28 and 90 days, kp of concrete using PPC is respectively 6.07 E-10 and 9.36 E-11 cm/sec. This is respectively only 80% and 50% of kp of concrete using PCI.

Discussion

The results of compressive strength, modulus of elasticity and permeability test of concrete made by using PCI and PPC show the same tendency i.e. the compressive strength and the modulus of elasticity increase and the permeability coefficient decreases with the increase of the hydration time. The development of this mechanical properties of concrete can be attributed to the growth of the hydration products with the increase of the hydration time.

It is well known that with the increase of the hydration time and under condition of adequate curing, the quantity of hydration products, especially C-S-H produced from the reaction of tricalcium silicate (C3S) and dicalcium silicate (C2S) of the binder with water (H_2O), increases. The increase of the quantity of C-S-H makes the bond between binder and aggregate getting stronger and the empty spaces that are originally occupied by water and cement particles dissolve and they are replaced by C-S-H so that the porosity of concrete reduces. This condition provides a major contribution to the increase in the compressive

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strength and modulus of elasticity in line with the reduce of the permeability of concrete with the increase of the hydration time [3-5].

From the test, it is also obtained that at early age, concrete using PPC initially produces lower compressive strength and modulus of elasticity and higher permeability coefficient compared to that using PCI. It is strongly related to the presence of pozzolan in PPC. It is known that the reactivity of the pozzolan is generally lower compared to Portland cement clinker. Blending pozzolan and Portland cement clinker will influence the reactivity of binder produced (PPC), and of course, the development of the mechanical properties of concrete made.

With the increase of the hydration time, it appears that concrete using PPC produces better mechanical properties than that using PCI, especially after the age of hydration has passed 20 days. Pozzolan blended in PPC contains mainly reactive silica and alumina. The purpose of a certain amount of pozzolan blended with Portland cement clinker in producing of PPC is to reduce the free lime $Ca(OH)_2$ produced by C3S and C2S hydration and simultaneously to produce additional hydration products, in particular C-S-H. Free lime produced from C3S and C2S hydration will react gradually with the reactive silica and alumina of pozzolan to form additional C-S-H and C-A-H. This process will reduce the size of large crystals such as $Ca(OH)_2$ and subsequently the additional C-S-H and C-A-H will fill large capillary cavities which are formed on a common Portland cement hydration process. So that, the porosity of the cement paste hydrates as well as the transition area between the cement paste and aggregate hydrates will be reduced significantly. Consequently, compressive strength and modulus of elasticity of concrete increase and its permeability decreases simultaneously [3, 4]. However, it appears that, only after the period of hydration is more than 20 days, the contribution of pozzolanic reaction to the mechanical properties of concrete using PPC can be seen. This condition gives better mechanical properties than concrete using PCI.

CONCLUSION

At the early age, the development of the mechanical properties of concrete using PPC are slower than that using PCI.

Concrete using PPC can show better mechanical properties compared to that using PCI only after the age of the hydration time is more than 20 days.

At the age of 90 days, concrete using PPC can produce higher compressive strength and modulus of elasticity, respectively about 8% and 15%, and lower permeability coefficient, about 50%, compared to concrete using PCI.

ACKNOWLEDMENTS

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