Characteristics of Pozzolan and Composite

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Characteristics of Pozzolan and Composite Portland Cement as The Materials for Sustainability Concrete

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Abstract – To support sustainable materials, the ordinary Portland cement production has been reduced since it left a high carbon footprint during manufacturing. As an alternative, the use of pozzolan Portland cement and composite Portland cement has been encouraged because they are more environmentally friendly. This paper examines some characteristics of cement made from pozzolan Portland cement (PPC) and composite Portland cement (PCC). The testing procedures were carried out on chemical and physical testing on PPC and PCC. In addition, the mechanical testing of concrete made from both types of Portland cement and their combinations were conducted under compression load. Furthermore, the surface hardness of the concrete was evaluated using a rebound hammer test. Concrete testing was conducted after the curing age of 7, 28, and 42 days. According to chemical examination, PPC has greater silica (SiO_2) and iron (Fe_2O_3) than those of PCC, whereas PCC has a higher lime (CaO) content. Compared to PPC, PCC shows faster initial and final setting time. This result is proportionally influencing the strength development of concrete. PCC concrete shows significant strength development at the earlier age. Meanwhile, PPC concrete reacts slower at the earlier age but it improves the compressive strength at the later age. The mix combination of 50% PPC and 50% PCC in concrete shows the highest average compressive strength and surface hardness. This combination achieves the average compressive strength of 30.27 MPa, 35.27 MPa, and 35.93 MPa respectively for 7, 28, and 42 days curing time. Furthermore, this concrete also shows the greatest characteristics of Young's modulus and surface hardness.

Keywords: sustainability concrete, pozzolan Portland cement, composite Portland cement

Introduction

Concrete is recognized as a sustainable material in construction because it has been used since in the past until now. Sustainability material, especially for building material, is such materials that enable to improve the quality of life and working conditions and reduce their negative impacts on the environment. Therefore, in terms of concrete, sustainability concrete means that it not only stays for such a long time application but also possess the properties to meet the requirement for sustainability materials as being demanded above.

Sustainability concrete is categorized as the concrete which enables to minimize energy and carbon dioxide (CO_2) during production, minimize water use, increase the use of recycled content, increase the use of environmental waste, minimize the process needs, minimize cost and society benefits. Portland cement is one of the important components in concrete production. Ordinary Portland Cement (OPC) is the most widely and commonly used cement in the world. This type of cement is manufactured to be powder by mixing fresh natural resources such as limestone and other raw materials which consist of argillaceous, calcareous, and gypsum. During cement manufacturing, it produces CO_2 emission which is divided into process emission by more than 50%, thermal emission by 40%, and others such as grinding and transporting by 10% (Jin, Chen, and Soboyejo, 2015; Rodgers, 2018; Singh and Subramaniam, 2019). For the shake of sustainable material issues, the use of alternative cement has been encouraged nowadays. The studies on the addition or replacement materials in cement to promote sustainability concrete have been published (Parande *et al.*, 2011; Al-Chaar, 2013; Assi *et al.*, 2018; Adesina and Olutoge, 2019; Mindess, 2019; Singh and Subramaniam, 2019). For instance, the use of natural pozzolan which was rice-husk ash and lime or (RHA-Lime) has been reported by (Adesina and Olutoge, 2019). It is found that RHA-Lime concrete achieves higher early strength than that of concrete control. Furthermore, considering the strength, RHA-Lime cement mixes are appropriate in the structural application and can replace conventional cement up to 25%. Therefore, it is potential to be a substitute material for conventional cement in concrete.

Current in Indonesia, Pozzolan Portland Cement (PPC) and Portland Cement Composite (PCC) are the types of alternative Portland Cement which are commonly found commercially. Ordinary Portland Cement (OPC) has rarely been found commercially. PPC and PCC employ natural and industrial waste which reduces environmental pollution and lower cost and emission during manufacturing. PPC is a hydraulic cement consisting of a homogeneous mixture of Portland cement with fine pozzolan, which is produced by grinding Portland cement clinker and pozzolan together or mixing evenly of Portland cement powder with pozzolan powder, or a combination of grinding and mixing, where the levels pozzolan 6 to 40% mass of Portland pozzolan cement. Meanwhile, PCC is a mixed hydraulic binder together with slag Portland cement and casts with one or more inorganic materials, or the result of mixing Portland cement powder with other inorganic powder. The inorganic materials include high blast furnace (blast furnace slag), pozzolan, silicate compounds, limestone, with a total content of inorganic material 6% - 35% of the mass of Portland composite cement (SNI 0302:2014, 2014; SNI 7064:2014, 2014)

However, people are still reluctant and questioning the quality of PCC and PCC. It is assumed that concrete made from PPC and PCC have lower strength than concrete made from OPC. As reported by (Al-Chaar, 2013) that concrete with the addition of pozzolan as cement replacement shows varying mechanical properties depending on the proportion of pozzolanic added during the mixing process. The strength of concrete with the addition of pozzolan has been seen significant at more than 28 days of concrete age. But at an earlier age, the mechanical strength is smaller than that of concrete with OPC. However, it is observed by (Parande *et al.*, 2011) that PPC exposed to severe environments such as sewage water and industrial wastewater shows better performance than OPC in both mechanical and electrochemical studies. The use of alternative cement is still debatable; therefore, this research is trying to study the properties of the PPC and PCC and the concrete made from both cement in terms of chemical composition, physical and mechanical properties experimentally.

Materials and Methods

Materials

PCC and PPC were the main materials utilized in this research. These types of cement were commonly available in the market in 50 kg packaging. The variation of both types of cement used in concrete is presented in the sub-section of concrete mixture proportion.

Crushed aggregate was used as coarse aggregate meanwhile, the fine aggregate was the natural type aggregate. The maximum size of coarse aggregate was 20 mm. The specific gravity of coarse and fine aggregate was 2.59 and 2.62 respectively. In addition, the water absorption of coarse aggregate was 1.68% whereas the water absorption of fine aggregate was 2.62%. The aggregate meets the requirement of Indonesian standard of aggregate for making concrete (SNI 03-1750-1990, 1990).

Concrete mixture proportion

To investigate the properties of concrete made from PPC and PCC, four mixture proportions were prepared as shown in Table 1. The first and second proportions were entirely made from cement type of PPC and PCC respectively. Then PPC and PCC were blended into two variations. The first was PPC 50% and PCC 50% and the second was PPC 75% and PCC 25%.

The variation of cement content in the mixture proportion was considered based on the chemical examination, where PPC contained more silica than PCC therefore a greater proportion of PPC was assumed to reach better concrete mechanical properties. The water-cement ratio was kept by 0.45 and the mixture proportion of each ingredient was kept the same except the cement content.

Table 1. Concrete mixture proportion

Cement Proportion	Water (kg)	Cement (kg)		Gravel (kg)	Sand (kg)
		PPC	PCC		
PPC 100%	246	451	–	934	771
PCC 100%	246	–	451	934	771
PPC (50%) : PCC (50%)	246	226	226	934	771
PPC (75%) : PCC (25%)	246	338	113	934	771

Method of testing

The specimen was concrete cylinders with a diameter size of 150 mm and a height of 300 mm. The testing was conducted on cement powder, cement paste, and concrete cylinder. Chemical testing was applied to cement powder to evaluate the composition of silica, calcium, and iron in PPC and PCC. The chemical composition of each cement was further considered as the proportion of blended cement as shown in Table 2. The physical examination was conducted on cement paste to evaluate the initial and final setting time of PPC and PCC. The testing was based on the Vicat Test procedure (SNI 03-6827-2002, 2002).

The mechanical testing was applied to the concrete cylinder. Prior to concrete casting, the concrete fresh properties were evaluated using a slump test. The hardened concrete was subjected to compression loading until failure after the curing age of 7, 28, and 42 days. Additionally, during compression testing, the concrete deformation was recorded to obtain the stress-strain curve and to analyze the Young's Modulus. Another physical testing to the concrete specimen was delivered using non-destructive apparatus which was rebound hammer testing to determine the surface hardness (SNI ASTM C805-2012, 2012). The entire testing methods is summarized in Table 2.

Table 2. Method of testing

Method of test	Measurement	Test result
Chemical testing	Chemical composition	Silica content Lime content Iron content
Physical Testing	Setting Time	Initial setting time Final setting time
	Workability	Slump value
Mechanical Testing	Compression loading and deformation	Compressive strength Young's modulus Stress-strain curve
Non-Destructive Testing	Rebound hammer	Surface hardness

Results and Discussions

Chemical composition

Table 3 shows the chemical composition of the PPC and PCC. PPC contains greater silica and iron than PCC meanwhile PCC contains greater lime than PPC. If silica and calcium react, they form tri-calcium silicates (C3S) and di-calcium silicates (C2S) compounds which provide strength and binding effect to the aggregate. The compounds have the composition that makes up 70-80% of cement. Of equal importance, PCC contributes to long term strength gaining due to higher lime content (Singh and Subramaniam, 2019).

Table 3. Chemical Composition

Composition (%)	Cement Type	
	PPC	PCC
Silica (SiO_2)	24.17	18.71
Lime (CaO)	66.7	72.45
Iron (Fe_2O_3)	3.21	2.14

Setting time

Figure 1 gives the initial setting time and final setting time of PPC and PCC. PCC has the fastest setting time both in terms of initial setting time and final setting time. On the other hand, PPC has the longest setting time. PPC setting time has a value of about 1.3 times the PCC setting time value. After both cement types are mixed equally, the results of the setting time show the values between the original values. PCC reacts faster than PPC due to higher lime content in PCC. This is in line with the findings of (Nawaz *et al.*, 2016; Jaafri *et al.*, 2019) showing that higher lime content leads to faster setting time.

A considerable amount of initial setting time is needed to provide concrete practitioners with the opportunity to work during the concrete manufacturing process. Short setting time can enable concrete hardening faster, therefore construction work can be finished faster because it is easy to dry. However, such this condition is not solely as the requirement in construction since it tends to induce more

shrinkage microcracks in concrete (Tjokrodimuljo, 2007). The final setting time indicates the chemical reaction of the cement with water is nearly complete.

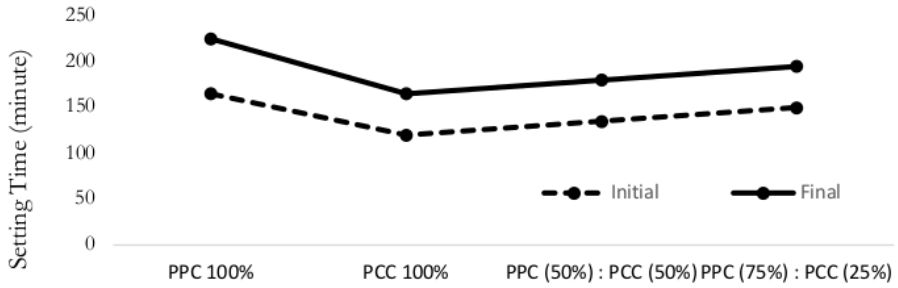

Figure 1. Setting time

Fresh concrete slump

Table 4 shows the fresh concrete slump. The slump value indicates the workability of the concrete. All mixtures show proper workability since the slump value adequate for a requirement of concrete work practical standard. However, PCC concrete has the lowest slump and the highest is shown by PPC concrete. PCC consists of more lime in which need more water to be workable. Therefore, the slump of PCC concrete decreases since the water-cement ratio was kept the same among the mixtures. It is reported that it needs to add more than 2% water to achieve the same workability when adding 10% lime to the concrete mixture (Nawaz *et al.*, 2016).

The slump value for concrete with the blended PPC and PCC are between the slump value of PPC and PCC. The greater proportion of PCC in concrete shows a lower value of slump. The higher value of the slump leads to a concreting process to be easier.

Table 4. Fresh concrete slump

Specimen	Slump (mm)
PPC 100%	95
PCC 100%	88
PPC (50%) : PCC (50%)	90
PPC (75%) : PCC (25%)	92

Compressive strength

The compressive strength of the concrete is presented in Figure 2. In general, PPC concrete has higher compressive strength than PCC concrete. PPC concrete show a normal strength development from 7 days until 42 testing days as required by code where the ratio of the strength of 7 days is around 0.8 times to the strength of 28 days and the ratio the strength of 42 days is around 1.1 times of the 28 days strength (SNI 03-2834-2000, 2000). On 7 days curing time, the compressive strength of PCC concrete is higher than that of PPC concrete. Due to faster setting time, then on 28 days, the compressive strength grows significantly which is almost the same as 42 days compressive

strength. Otherwise, PPC concrete reacts slower at the earlier age but it improves the compressive strength at the later age.

The slower strength development of PCC concrete at the earlier age than that of the commercially available Portland cement concrete has been reported by (Singh and Subramaniam, 2019). Similarly, it is also confirmed that PCC concrete achieved a lower compressive strength.

Although PPC has excellent characteristics on preliminary test results, in the form of concrete, concrete with a mixture of 50% PPC and 50% PCC shows the highest value on each curing day. Likewise, concrete with the ratio of PPC 75% and 25% PCC even though prior to the testing age of 28 days shows a lower compressive strength, but after 28 days shows a significant compressive strength development which is similar to concrete with a ratio of 50% PPC and 50% PCC. After 42 days of curing time, concrete with an identical proportion of PPC and PCC reaches the highest compressive strength among the mixture proportion. This combination achieves the average compressive strength of 30.27 MPa, 35.27 MPa, and 35.93 MPa respectively for 7, 28, and 42 days of curing time. It is assumed that the continued pozzolanic reaction occurs properly and contributes strength in the later stage.

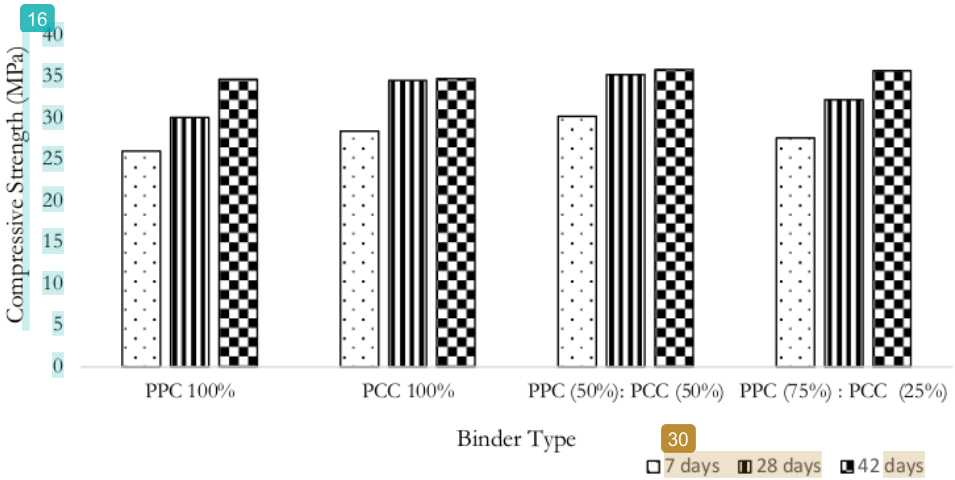

Figure 2. Concrete compressive strength

Young's Modulus

Young's modulus is obtained based-on the secant modulus of elasticity procedure. The value of Young's modulus corresponds to the compressive strength. Young's modulus increases with increasing concrete age. Concrete with binder mixture of 50% PPC and 50% PCC produces the concrete with the highest Young's modulus value. However, in general, the value of Young's modulus for all concrete types is still in the range of static modulus of elasticity for normal concrete which is around 20000-30000 MPa. Figure 3 presents Young's modulus obtained for 7, 28, and 42 days in each binder type.

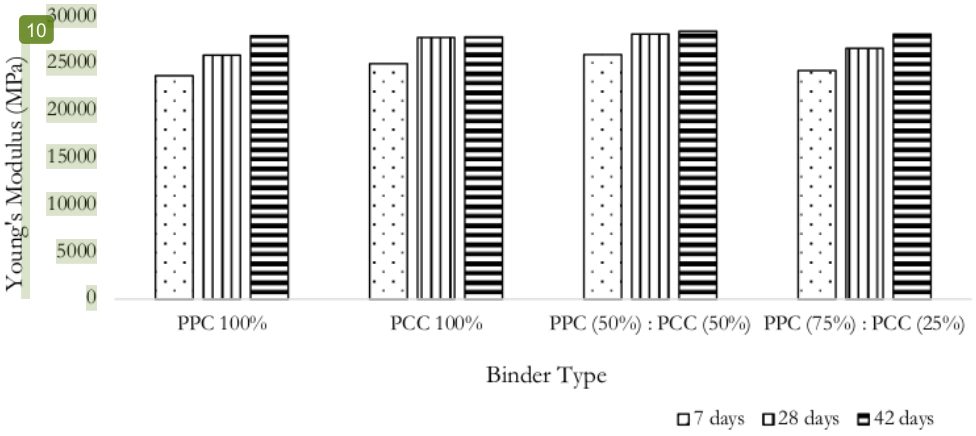

Figure 3. Concrete Young's modulus

Stress-strain curve

In general, all types of concrete show a similar shape where the curve initiates from the proportional line between stress and strain, and then it turns into a plastic condition before the ultimate failure when the strain approaches 0.0025-0.003. The proportional limit stress in all types of concrete is almost similar to about 30% of the maximum stress. Beyond this limit, the microcracks appear and as the increase in axial load, the larger cracks are formed gradually until the peak stress reached.

Furthermore, on the later stage of curing time, concrete behaves more ductile because there seems to be an extension of the curve after the maximum stress. Ductile material is more preferable in construction to prevent sudden failure. The graph of the stress-strain relationship is illustrated in Figure 4-6 for each curing age.

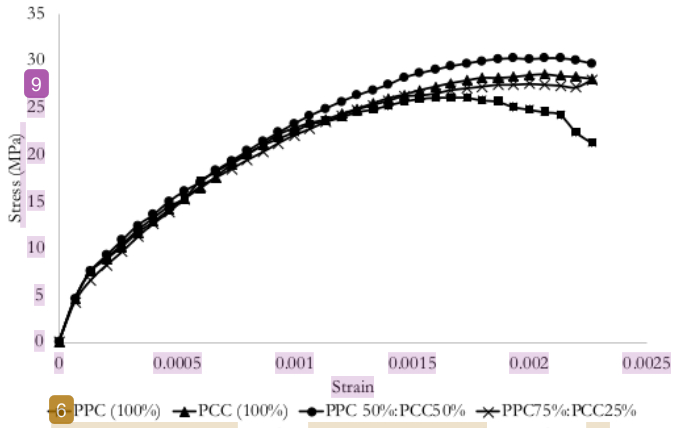

Figure 4. Stress-strain curve under compression load at 7 days of curing age

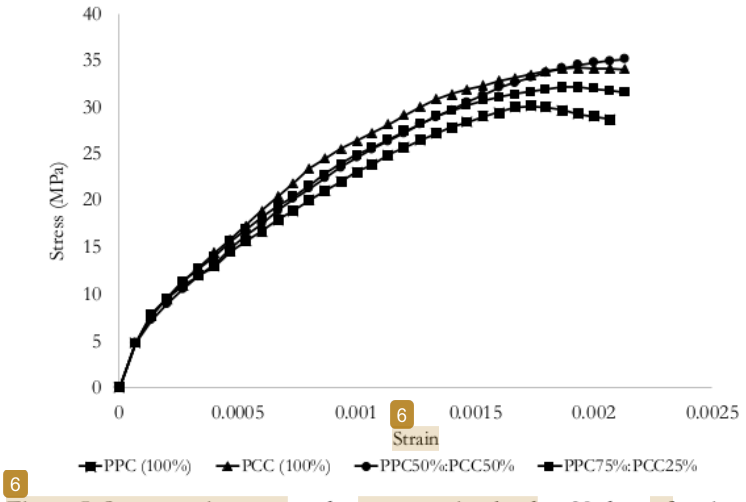

Figure 5. Stress-strain curve under compression load at 28 days of curing age

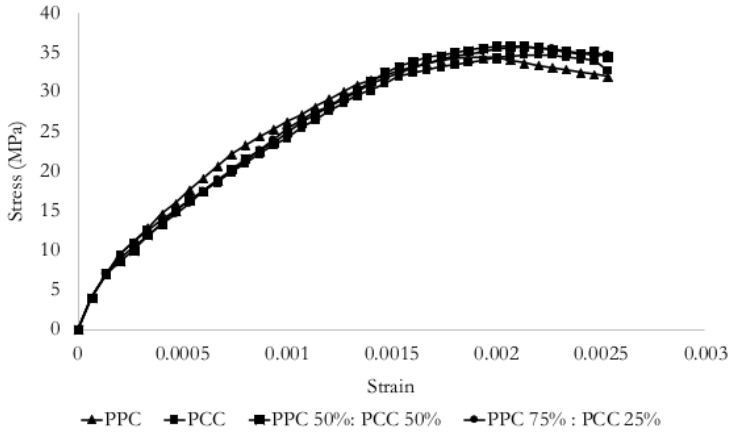

Figure 4. Stress-strain curve under compression load at 42 days of curing age

Surface Hardness

The surface hardness of concrete was measured with a rebound hammer test. The rebound number is influenced by several factors, one of the factors is the type of cement (Szilágyi, Borosnyói, and Zsigovics, 2015). Hammer rebound number is generally associated with concrete compressive strength. However, in this paper, the rebound numbers are utilized to evaluate the surface hardness of each type of concrete made by different types of binders to evaluate the effect of cement type of concrete surface hardness. Table 5 shows the rebound number of concretes made of PPC and PCC and the blended between them.

In general, on each curing time, the surface hardness of each concrete type is not significantly different. At an early age, the lowest rebound number belongs to PPC concrete; however, at a later age, it reaches the rebound number almost similar to PCC concrete. Furthermore, the concrete with mixture of PPC (50%): PCC (50%) shows the highest surface hardness in age concrete curing time. The results of concrete surface hardness are in line with the concrete compressive strength.

Table 5. Concrete rebound number

Curing time (days)	Rebound number			
	PPC (100%)	PCC (100%)	PPC(50%):PCC(50%)	PPC(75%):PCC(25%)
7	25.5	26.6	26.7	26
28	28	28.5	28.8	28.4
42	29.7	29.9	30.3	30

Characteristic review of PPC, PCC, and the mixed cement

PCC in which has higher lime content produces concrete with a higher composition of C3S. C3S is a compound that has a high rate of hydration so it dries faster indicated by the lowest setting time as mentioned in the sub-section of setting time and it hardens with a high initial compressive strength. On the other hand, PPC has a more dominant of C2S, therefore, the concrete consisted of this cement shows a lower hydration rate at the initial and can provide high compressive strength in later age (Tjokrodimuljo, 2007).

Despite PPC presents excellent properties on preliminary examination (chemical composition, physical and workability properties), the concrete with blended cement of PPC and PCC with the ratio of 50%:50% respectively provides the best mechanical strength when this binder type is used to make the concrete. This is because the influence of C3S chemical compounds from PCC and C2S compounds from PPC performs the best reaction to produce the highest compressive strength of concrete. Considering the concrete composition of 75% PCC and 25% PPC, in spite of its initial compressive strength is low, however, at 42 days testing, the compressive strength is almost equal to the highest concrete compressive strength. This occurs due to the continuous pozzolanic reaction from the hydration process.

Conclusion

PPC has the characteristics of silica content, physical, and workability properties that are more prominent than either PCC or mixture between PPC and PCC. However, when used in making concrete, PPC concrete has lower characteristics than the mixture between PPC and PCC.

Concrete with a mixture of 50% PPC and 50% PCC show a good compressive strength development before 28 days. However, after 28 days the development of the compressive strength is rather constant. Among all the concrete types, this concrete achieves the greatest average compressive strength in each curing time. On the other hand, for the concrete with blended cement of PPC 75% and 25% PPC, despite the lower initial compressive strength but it's 42 days compressive strength is almost equal to the highest compressive strength, which produced by the concrete with a mixture of 50% PPC and 50% PCC. Furthermore, concrete made from the blended of PPC (50%) and PCC (50%) also shows the greatest characteristics of Young's modulus and surface hardness.

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