Toward Green Concrete: Replacing Clinker with Trass materials to Produce

by @Turnitin Jogja

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Toward Green Concrete: Replacing Clinker with Trass materials to Produce Portland Pozzolan Cement (PPC)

ABSTRAK

Trass is a pozzolanic additive from soft rock or soil layers derived from volcanic ash. This component can replace clinker in the manufacture of cement. The advantages of trass in cement manufacture are that it can regulate the reaction of calcium hydrate cement, increase chemical stability, and improve mechanical properties. This study investigates the effect of adding trass to the quality of Portland Pozzolan Cement (PPC) in terms of compressive strength and setting time. In addition, it also observed the chemical and physical properties of cement. During the study, the substitution of trass on the clinker was in the range of 0 – 40 % of the total mass. In addition, gypsum and limestone compositions were set at 3% and 5%, respectively. In other words, clinker was added at a variation of 52 to 86 % (w/w). In this study, the fineness factor of the cement mixture was maintained in the range of 3800 - 4000 cm^2/gr. The effect of the contribution of trass on the cement mixture was measured by testing the chemical and physical properties, the compressive strength test of the mortar, and the setting time test at the age of 1, 3, 7, and 28 days. The results showed that the addition of 21% trass significantly increased the mechanical properties of PPC at the age of 28 days, where the compressive strength was 371 kg/cm2, the initial setting time was 190 minutes, and the maximum final setting time was 290 minutes.

Keywords: additives, clinker ratio, composite, compressive strength

1. INTRODUCTION

Indonesia is a developing country that continues to grow in various population needs such as housing, toll roads, office buildings, hospitals, and others [1] [2]. Consequently, construction in Indonesia is increasing along with the increasing development of Indonesia. As is known, cement is one of the main essential ingredients in building construction, so cement is one of the strategic commodities in the country [1]. In 2017, Indonesia exported 220,000 tons of cement while at the same time imported 2.4 million tons. This data indicates that Indonesia still has to increase domestic cement production, quantity, and quality [2].

Portland Pozzolan Cement (PPC) is a hydraulic cement consisting of a homogeneous mixture of portland cement and pozzolanic material containing silica and alumina [3] [4] [5]. This material does not have binding properties like cement [6]. The use of pozzolanic materials in cement production provides many advantages for the company and the environment [7] [8] [9]. For companies, pozzolanic materials can reduce clinker consumption in the cement production process to reduce production costs [10]. Meanwhile, for the environment, the use of PPC can reduce CO_2 emissions due to the clinker combustion process [1] [11].

Portland Pozzolan Cement has distinctive properties and many advantages, including high strength, better workability, and lower heat of hydration, so it is not easy to crack and has resistance to sulfates and salts [1] [12]. Therefore, PPC is suitable for construction on the coast and swamps [13] [7].

Previous researchers reported two types of pozzolan, namely natural pozzolan and artificial pozzolan [14] [15]. Trass is a natural pozzolan in the form of soft rock or soil layers derived from volcanic ash [16]. Meanwhile, an example of artificial pozzolan is fly ash which has also been studied by other researchers and can be used as a clinker substitute [17] [12] [18]. Trass is an alternative material as a substitute for clinker in cement manufacture while still prioritizing the required specifications [6] [19]. It was reported that a good proportion of trass could improve setting time and compressive strength: initial compressive strength and used compressive strength [20]. Then, investigating pozzolanic material proportion as clinker substitution has attracted some researchers. It needs to be carried out to increase production cost efficiency and the quality of PPC products [21]. The proportion of pozzolanic materials used in manufacturing PPC products is attractive.

Prior to use, raw materials must be analyzed to ensure the quality of the resulting product. From various works of literature, X-ray fluorescence spectrometry (XRF) is commonly used as an instrument of qualitative and quantitative analysis [1]. This type is a non-destructive analytical method used to identify and determine the concentration of compounds contained in solids. This study uses XRF type Energy-dispersive X-ray Fluorescence (EDXRF) to determine the chemical content of PPC. In general, this study aims to determine the effect of trass substitution on clinker for PPC quality, namely compressive strength and setting time.

2. MATERIALS AND METHODS

2.1 materials and tools

This research uses tools such as a crusher, sieve Shaker, 10 kg scale, ACMEL Blaine Machine, mixer 300/260 L. Flat blade, Vicat E055N, measuring cup with 200 mL and 250 mL, filter paper, grinding machine Herzog. The materials used include Tiga Roda brand Cement, limestone, gypsum, trass, Coarse aggregate size 10 – 20 mm, fine aggregate (sand), distilled water, ethylene glycol $(CH_2OH)_2$, 0.5 N HCl solution, 1% PP indicator.

2.2 procedures

The study consisted of four steps: preparation of raw materials, proportion design, testing, and analysis. Figure 1 shows the research diagram.

2.2.1 crushing and mixing

Limestone raw materials that are still large are reduced through two stages: a jaw-type primary crusher and a roller-type secondary crusher to obtain a fine particle size. After that, the fine material is filtered with a sieve shaker to obtain a uniform size of 45μm sieve. On the other hand, the pozzolanic trass was dried to remove its moisture content in an oven at 105^{o}C for 24 hours. Furthermore, all PPC materials, namely clinker, limestone, gypsum, and trass in a specific composition with a total weight of 5 kg, are fed into the turbula machine for 1 hour so that they are thoroughly mixed.

2.2.2 blaine's determination

This stage determines the PPC fineness value to conform to the ASTM C340 standard [22]. The cement sample is fed into the ACMEL machine weighing 5 g. Under the standard, if the Blaine value is less than 3800, then the sample must be returned to the grinding process, but if the Blaine value is more than 4000, then the sample cannot be used or, in other words, rejected.

2.2.3 flow determining

This step is the preparation of cement mortar to meet the value of workability according to the standard. First, prepare 450 grams of PPC, 2750 grams of sand, and some water following the procedure described in the standard. After that, the mixture of PPC and water is fed into the ring flow table for 60 seconds. Then lift the ring and start the flow machine for 20 seconds. Finally, measure the dough using a ruler from all 4 sides. If the measurement results are 110 ± 5 cm, it can be continued to the casting process, but if not, it must be re-mixed by adjusting the amount of water.

2.2.4 casting

This process is to compact the cement material so that it is ready to be used for the curing stage. First, the mortar mixture was put into the mold of the test specimen until it filled half of the parts, then flattened and pierced 32 times. After that, add another half and repeat the punctures 32 times. Finally, the test object was stored in a cabinet for 24 hours with the top surface in contact with humid air but must be avoided from water droplets.

2.2.5 curing

After 24 hours, the specimen is withdrawn from the cabinet and released from the mold. The hardened mortar is ready for compressive strength testing. The specimens were immersed in lime water and stored back in the cabinet for 3 days, 7 days, and 28 days. Nevertheless, before that, the researcher gave the code and date to the test object for identification purposes.

2.2.6 loss of ingnition (loi) test

A gram sample is fed into the furnace. It works at a temperature of 1050°C for 1 hour to determine the Loss of Ignition (LOI) in the PPC sample. After cooling for about 10 minutes, weigh the cup and calculate the LOI value using the formula:

$$LOI(\%) = \frac{(W_0 + W_1) - W_2}{W_1} x\ 100$$

Where: Wo is the weight of the empty cup, W_1 is the weight of the sample, and W_2 is the weight of the cup + sample after being heated.

2.2.7 x-ray fluorescence (xrf) test

This test is to determine the chemical composition of cement. Place the sample in the sample container of the XRF instrument weighing 0.7 g. Condition the XRF instrument according to the sample being analyzed. XRF works because the sample is shot with an x-ray beam, and after about 4 minutes, the analysis data will automatically appear on the monitor screen.

2.2.8 normal consistency test

This test determines the amount of water needed to prepare hydraulic cement paste to have normal workability. To start, prepare a weight of 650 grams of cement and some water following the procedure described. Then, the cement and water mixture was stirred at low speed for 30 seconds. After that, let the mixture sit for 15 seconds before being stirred again at medium speed for 60 seconds. Then, the test object is formed into a ball with both hands (wearing rubber gloves) and then inserted into a large hole in the Vicat tool, namely a cone ring with a height of 40 ± 1 mm and a flat plate, as can be seen in Figure 2. a. Immediately after, pass the balls of pasta on the vicat ring. Then set the indicator to zero on the scale and remove the bar immediately. Finally, after 30 seconds, the paste will be at its normal consistency when the stem is 10±1 mm.

2.2.9 setting time test

This test is carried out on a cement paste that is stiff enough to withstand the pressure. The cement paste from the normal consistency test stage that met the test specifications was left in a humid room 30 minutes after molding. Then, penetrate with a 1 mm diameter needle every 15 minutes until the penetration reaches 25 mm. It should be noted that during the test, the equipment must be vibration-free, and the needle should be cleaned after each use and ensure that the needle remains straight.

2.2.10 compressive strength test

This test is carried out to determine how much strength the mortar has against pressure. The initial compressive strength test is carried out by placing the test object on the pressure table of the compressive strength tool. The compressive strength method was carried out using a 50 mm cube mold, as Figure 2. b shows. First, after the computer and the compressive strength tool are turned on, observe the movement of the graph shown on the computer screen, then record the maximum value of the load that the test object can withstand until the test object breaks. The goal to be achieved is to determine whether the cement has met specifications or not.

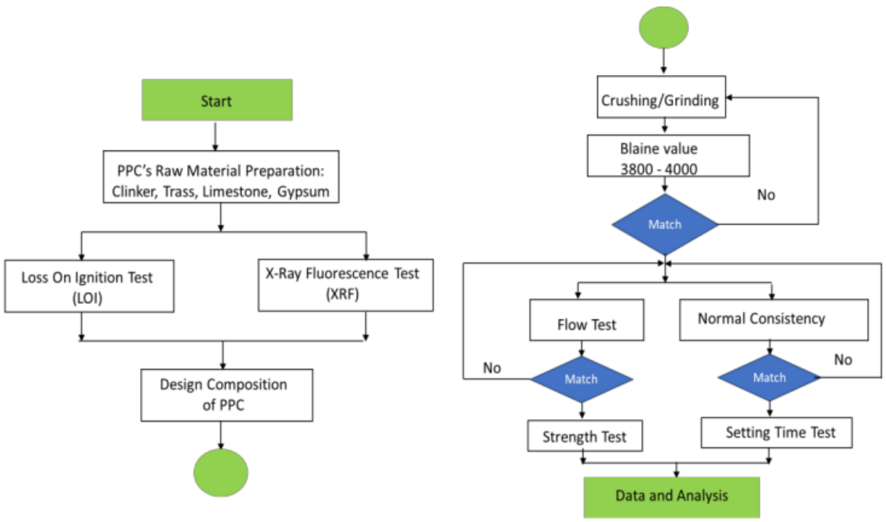
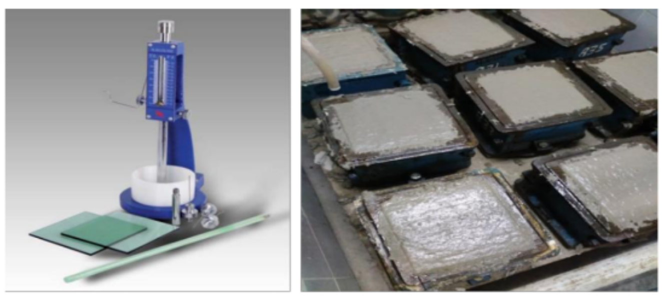


Figure 1. Research Diagram



(a) (b)

Figure 2. Vicat tools (2a) and Cube molds (2b)

3. RESULTS AND DISCUSSION

3.1. raw material preparation and design of PPC

In this research, 5,000 g of Portland Pozzolan Cement (PPC) is made by grinding clinker, gypsum, limestone, and trass together to produce the desired smoothness. The PPC composition was prepared with the addition of trass in the range of 0 - 40 %. The limestone and gypsum ratios were fixed at 3 and 5 % (w/w). The percentage of clinker, gypsum, limestone, and trass is 100 percent. Table 1 shows the composition of PPC–with eight variations in the amount of trass.

Moreover, the fineness factor is kept in the range of 3850±50 cm^2/gr, as shown in Table 2. This value is under the standard specifications of PPC according to SNI standards. The data shows that all the fineness of samples had met the specific Blaine surface for PPC, namely 3800-4000 cm^2/gr [23].

Table 1. Design of PPC

No.	Code	Raw Material Composition (g)				Total
		Clinker	*Limestone*	*Trass*	*Gypsum*	g
1	Blanko	4600	250	0	150	5,000
2	PPC–A	4300	250	300	150	5,000
3	PPC–B	4050	250	550	150	5,000
4	PPC–C	3800	250	800	150	5,000
5	PPC–D	3550	250	1050	150	5,000
6	PPC–E	3300	250	1300	150	5,000
7	PPC–F	3050	250	1550	150	5,000
8	PPC–G	2800	250	1800	150	5,000
9	PPC–H	2600	250	2000	150	5,000

Table 2. Fineness analysis

Code	PPC-A	PPC-B	PPC-C	PPC-D	PPC-E	PPC-F	PPC-G	PPC-H
(cm^2/g)	3990 ±50	3911 ±50	3966 ±50	3961 ±50	3860 ±50	3895 ±50	3915 ±50	3830 ±50
Target Blaine: 3800-4000 cm^2/gr								

3.2. impact of trass substitute on compressive strength

As shown in Table 3 and Figure 3, the compressive strength of mortar from day 1 to day 28 increases. Unfortunately, at the same time, it can also be seen that with the addition of the trass concentration, there is a decrease in the compressive strength values for all PPC samples [24]. These results are presumably because the CaO content in each sample decreases with increasing trass content which strongly agrees with [6]. It is clear that when referring to SNI 0302-2014 regarding Portland Pozzolan Cement, it can be seen that the results obtained for the PPC-G and PPC-H samples do not meet the criteria for all types of PPC.

PPC-A and PPC-B samples are the most superior results compared to other samples. Interestingly, the substitution of trass for clinker is quite large, namely 6 and 11%; besides reducing the cost of making clinker, it can also reduce fuel consumption. In addition, the PPC-C to PPC-F samples also meets the standard for compressive strength. It is close to reported by [25] [26] [14] [27].

Table 3. Physical properties of PPC in Comparation with SNI 15-0302-2004

Sample	Setting time (min.)		Compressive Strength (kg/cm^2)		
	Initial	Final	3 Days	7 Days	28 Days
SNI	Original: Min. 45	Final: Max. 420	IP-U Min. 125	IP-U Min. 200	IP-U Min. 250
			IP-K Min. 110	IP-K Min. 165	IP-K Min. 205
BLANKO	168	257	180	232	305
PPC-A	140	230	233	302	371

PPC-B	150	240	222	281	339
PPC-C	155	245	212	274	334
PPC-D	165	255	188	251	313
PPC-E	170	260	166	223	294
PPC-F	175	265	137	200	262
PPC-G	185	275	109	157	234
PPC-H	190	280	78	121	191

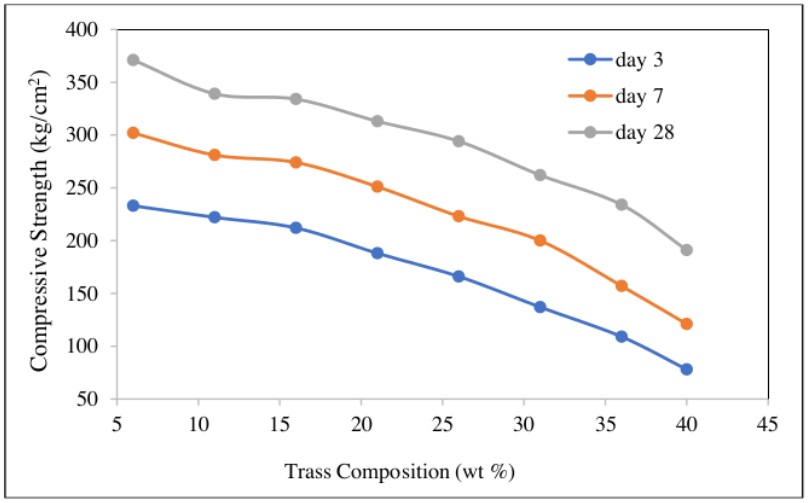


Figure 3. Impact of Trass on the compressive strength

3.3. impact of trass substitute on setting time

In terms of setting time, Table 3 also shows that the more trass content in the mortar, the longer the initial and final setting times. The need for water increases with the increase in trass in each sample. However, the good news is, in the setting time test, as Table 3 and Figure 4 show, all PPC samples met the SNI 0302-2014 standard, although the PPC-G and PPC-H samples still could not be used because the samples did not meet the compressive strength standards. The effect of adding trass to the compressive strength of mortar and setting time [28]. Figure 4 shows the effect of adding trass on PPC setting time.

3.4. impact of trass substitute on chemicals content

In terms of chemical content, the things that need to be analyzed for PPC are Loss on Ignition (LOI), MgO, and SO_3. Referring to SNI 0302-2014, the maximum LOI content for all types of PPC is 5%, MgO 6%, and SO_3 4% [1]. Based on the research results obtained as presented in Table 4 and Figure 5, the PPC-E to PPC-H samples cannot be used because the LOI value contained in the sample is more than 5%, even though the MgO and SO_3 content is only around 1-2 % [29]. The results of testing the chemical content of each sample in this study, only four samples meet all SNI 0302-2014 standards, namely PPC-A, PPC-B, PPC-C, and PPC-D.

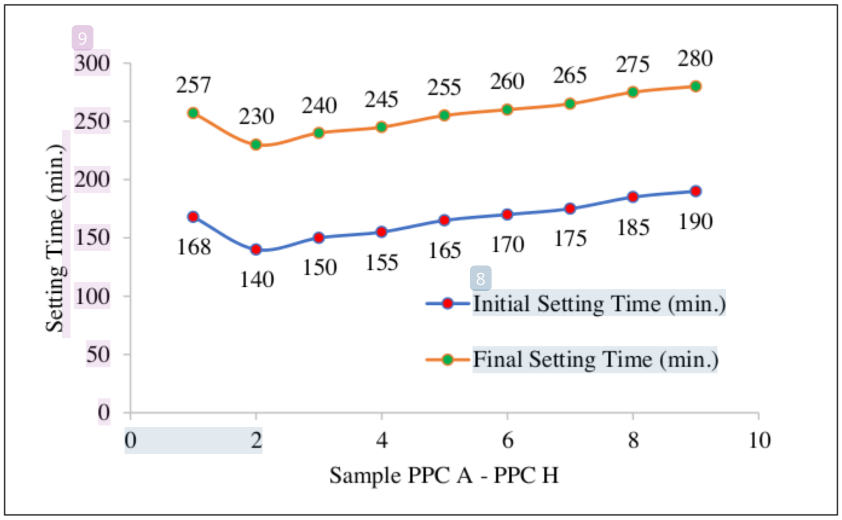


Figure 4. Impact of Trass on setting time

This study resulted that the PPC-A sample gave the best test results for all types of physical and chemical tests compared to other samples. However, the proportion of the PPC-A sample is not the best because the substitution of trass for the clinker content in this sample is the least, which is only 6%, so fuel consumption is still high and has an impact on emissions that are still high during the next production. It also shows that the PPC-B, PPC-C, and PPC-D samples, meet all test standards. A high enough trass content of up to 21% can reduce fuel consumption during clinker production, so this sample can be considered a remarkable proportion in this study.

Table 4. Chemical Properties of PPC (n = 2; ± SD)

Sample	LOI	MgO	SO_3
	(%)	(%)	(%)
Trass	2.86±0.030	0.79±0.030	0.03±0.130
Gypsum	19.76±0.055	0.01±0.280	42.54±0.280
Limestone	-	1.99±0.015	6.35±0.015
Clinker	0.55±0.020	2.89±0.065	6.66±0.065
Blanko	5.01±0.015	2.81±0.030	1.54±0.030
PPC-A	3.82±0.015	2.56±0.195	1.63±0.025
PPC-B	4.08±0.125	2.47±0.090	1.60±0.020
PPC-C	4.23±0.145	2.38±0.020	1.54±0.035
PPC-D	4.59±0.115	2.30±0.030	1.46±0.030
PPC-E	5.07±0.025	2.23±0.005	1.44±0,010
PPC-F	5.37±0.040	2.09±0.030	1.40±0.005
PPC-G	5.42±0.135	2.04±0.050	1.32±0.045
PPC-H	5.35±0.005	1.93±0.010	1.29±0.025

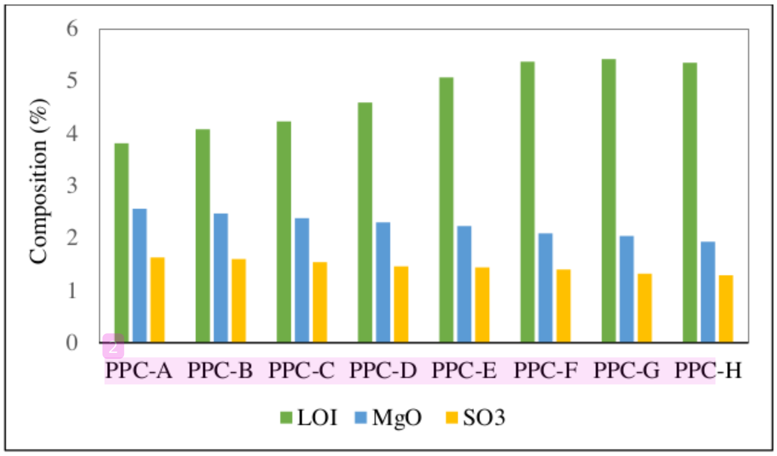


Figure 5. Impact of Trass on Chemical Content

Of all the existing samples, the proportion in the PPC-D sample is the optimum resulting from this study. Although the compressive strength results produced by the PPC-D sample are the lowest and the initial-late setting time is the longest compared to the PPC-A to PPC-C samples, all the test results still meet the existing standards for PPC. In addition, the trass content of PPC-D is the highest compared to the other three samples, which is 21%, so it has a significant impact on reducing the use of clinker, which has implications for less fuel consumption during the combustion process. The resulting emissions will also be much reduced [30].

4. CONCLUSION

Based on a series of experiments and observations that have been carried out, some conclusions can be drawn as follows:

1. The substitution of trass for clinker in PPC has a significant effect on the physical and chemical characteristics of the resulting PPC cement.
2. The addition of trass to PPC up to 21% positively affected both compressive strength and mortar setting time. However, when the trass composition is more than 21%, it decreases the cement strength and prolongs the setting time. Besides that, the LOI value produced is also higher.

5. ACKNOWLEDGMENT

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6. REFERENCES

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