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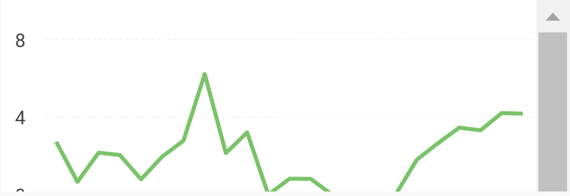

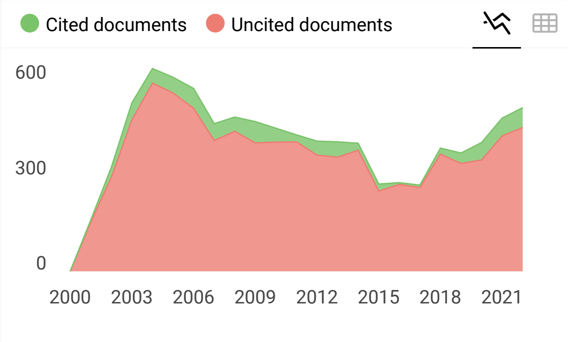

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Toward Green Concrete: Replacing Clinker with Trass Materials to Produce Portland Pozzolan Cement

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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/g. 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/cm^2, the initial setting time was 190 min and the maximum final setting time was 290 min.

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 alongwith the increasing development of Indonesia. As 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 tonnes of cement while at the same time imported 2.4 million tonnes. 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 [3-5]. 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 [7-9]. For companies, pozzolanic materials can reduce clinker consumption in the cement production process, reducing 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 sulphates and salts [1,12]. Therefore, PPC is suitable for construction on the coast and swamp areas [7,13].

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 flyash which has also been studied by other researchers and can be used as a clinker substitute [12,17,18]. 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

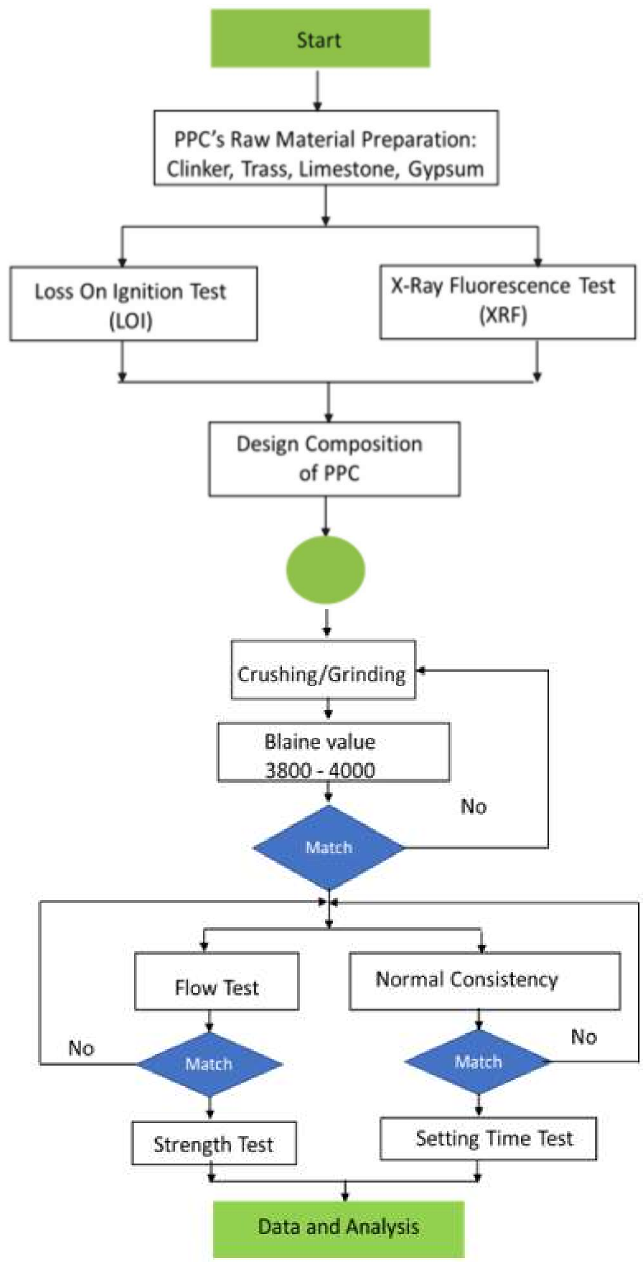

Figure 1. *Research diagram*

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. MATERIAL AND METHOD

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 and 1% phenolphthalein indicator.

2.2 Experimental procedure

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

2.2.1 Crushing and mixing : Large limestone were reduced through two stages: a jaw-type primary crusher and a roller-type secondary crusher to obtain fine particle size. After that, the fine material was filtered with a sieve shaker to obtain a uniform size of 45 μm. On the other hand, the pozzolanic trass was dried to remove its moisture content in an oven at 105^{0}C for 24 hr. Furthermore, all PPC materials, namely clinker, limestone, gypsum and trass in a specific composition with a total weight of 5 kg, were fed into the turbula machine for 1 hr so that they are thoroughly mixed.

2.2.2 Blaine determination: This stage determines the PPC fineness value to conform to the ASTM C340 standard [22]. The cement sample was 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 is rejected.

2.2.3 Flow determination : This step is the preparation of cement mortar to meet the value of workability according to the standard. First, 450 gm of PPC, 2750 gm of sand and some water were mixed following the procedure described in the standard. After that, the mixture of PPC and water was fed into the ring flow table for 60 sec. Then the ring was lifted and the flow machine was started for 20 sec. Finally, the dough was measured using a ruler from all 4 sides. If the measurement results are 110 ± 5 cm, it can be contin-

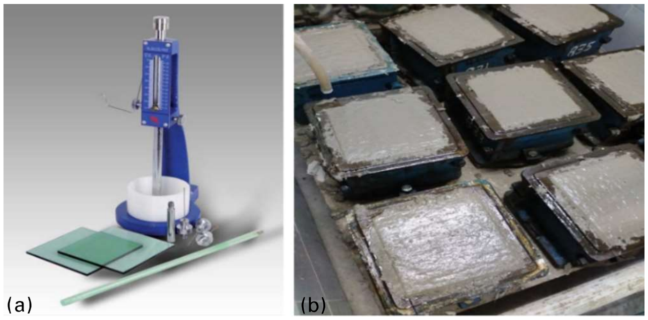

Figure 2. *(a) Vicat tools and (b) cube moulds*

ued 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 mould 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 hr with the top surface in contact with humid air but prevented from water droplets.

2.2.5 Curing: After 24 hr the specimen is withdrawn from the cabinet and released from the mould. 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 test : A gram sample is fed into the furnace. It was heated at a temperature of 1050°C for 1 hr to determine the loss of ignition (LOI) in the PPC sample. After cooling for about 10 min, the cup was weighed and the LOI value was calculated using the formula:

$$LOI\ (\%) = \frac{(W_0 + W_1) - W_2}{W_1} x100 \quad ...(1)$$

Where W_0 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 test : This test is to determine the chemical composition of cement. Place the sample in the sample container of the x-ray fluoresence (XRF) instrument weighing 0.7 g. Condition the XRF instrument according to the sample being analyzed. XRF works as the sample is shot with an x-ray beam and after about 4 min, 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 650 gm of cement and some water following the procedure described. Then, the cement and water mixture was stirred at low speed for 30 sec. After that, let the mixture sit for 15 sec before being stirred again at medium speed for 60 sec. 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 2a. Immediately after, pass the balls of paste on the Vicat ring. Then set the indicator to zero on the scale and remove the bar immediately. Finally, after 30 sec, 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 for 30 min after moulding. Then, penetrate it with a 1 mm diameter needle every 15 min 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 mould, as shown in figure 2b. Using computer and the compressive strength tool, 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 is to determine whether the cement has met set specifications or not.

3. RESULT AND DISCUSSION

3.1 Raw material preparation and design of Portland pozzolan cement

In this research, 5,000 g of Portland pozzolan cement (PPC) was made by grinding clinker, gypsum, limestone and trass together to produce the desired smoothness. The PPC composition was prepared with the addition

Table 1. *Design of Portland pozzolan cement*

Code	Raw material composition (g)				Total (g)
	Clinker	Limestone	Trass	Gypsum	
Blank	4600	250	0	150	5,000
PPC–A	4300	250	300	150	5,000
PPC–B	4050	250	550	150	5,000
PPC–C	3800	250	800	150	5,000
PPC–D	3550	250	1050	150	5,000
PPC–E	3300	250	1300	150	5,000
PPC–F	3050	250	1550	150	5,000
PPC–G	2800	250	1800	150	5,000
PPC–H	2600	250	2000	150	5,000

Table 2. *Fineness analysis*

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

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%. 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/g, 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/g [23].

3.2 Impact of trass substitute on compressive strength

As shown in table 3 and figure 3, an increase in the compressive strength of mortar from day 1 to day 28 is observed. 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

Table 3. *Physical properties of Portland pozzolan cement in comparison to 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
Blank	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

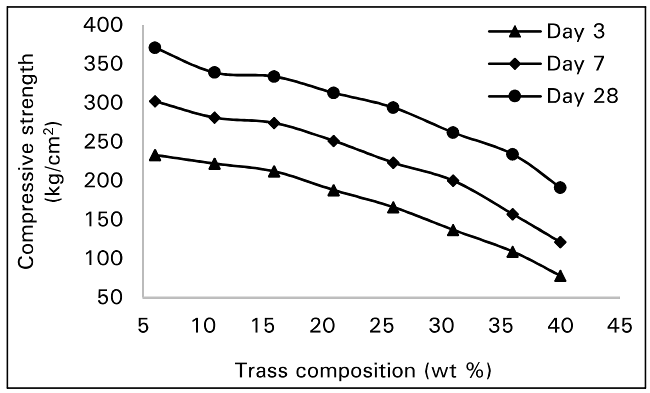

Figure 3. *Impact of trass on the compressive strength*

sample decreases with increasing trass content which strongly agrees with Kapeluszna [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 PPC. PPC-A and PPC-B samples showed best 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 study reported by Kazemian, Tang, Sunarno and Priastiwi [14,25-27].

3.3 Impact of trass substitution on setting time

In terms of setting time, table 3 also shows that the

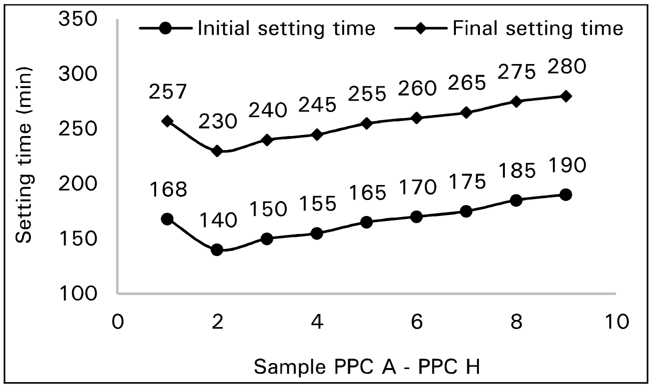

Figure 4. *Impact of trass on setting time*

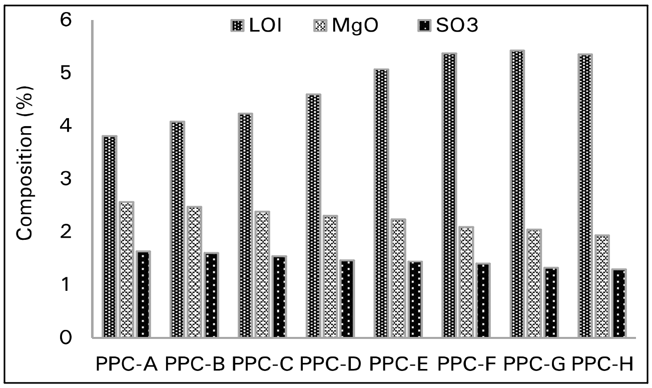

Figure 5. *Impact of trass on chemical content*

more trass content is in the mortar, the longer is the initial and final setting time. The need for water increases with the increase in trass in each sample. However, 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 [28]. Figure 4 shows the effect of adding trass on PPC setting time.

3.4 Impact of trass substitution on chemical content

In terms of chemical content, PPC was analyzed for 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 is 6% and SO_3 is 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% [3]. 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.

Table 4. *Chemical properties of Portland pozzolan cement (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
Blank	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

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 upto 21% can reduce fuel consumption during clinker production, so these samples can be considered a remarkable proportion in this study. Of all the existing samples, the proportion in the PPC-D sample is optimum 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 [29].

4. CONCLUSION

Based on series of experiments and observations that have been carried out, some conclusions can be drawn as follows. The substitution of trass for clinker in PPC has a significant effect on the physical and chemical characteristics of the resulting PPC cement. The addition of trass to PPC upto 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.

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