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COMPRESSIVE STRENGTH OF REACTIVE POWDER CONCRETE CONTAINING BAMBOO LEAF ASH

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ABSTRACT

The development of reactive powder concrete as an ultra-high-performance-concrete construction material in Indonesia has a very high prospect, mainly due to the availability of local raw materials. The original RPC composition developed in the 1990s consists of Portland cement, silica fume, silica sand, quartz powder (optional), and micro steel fibers (optional). This research is an initial study of the use of bamboo leaf ash as silica fume substitution to produce RPC with local Indonesian material. In this study, RPC mixture was manufactured base on the existing of previous research. Synthesized bamboo leaf ash (SBLA) was utilized to replace 100% of silica fume content in the mix. The experimental results confirmed that replacing of all silica fume volume in the mix with SBLA is promising to be applied as pozzolanic material to produce RPC. In this study, The RPC mixture containing 25% SBLA of cement mass was able to maintain a 73.84% compressive strength of the control mix. Furthermore, a mean compressive strength of plain RPC of 63.87 MPa was developed using at 28th days standard curing with low cement content.

KEY WORDS: reactive powder concrete; synthesized bamboo leaf ash; pozzolanic material

INTRODUCTION

Reactive powder concrete (RPC) as an ultra-high-performance-concrete (UHPC) is a new man-made brittle material that developed by Richard and Cheyrezy in 1990s. This first RPC has compressive strengths ranging from 170 MPa to 230 MPa (RPC 200) and can be achieved to 810 MPa (RPC 800) using steel aggregate in laboratory conditions. A non-fibred RPC 200 was consist of Portland cement, silica fume, silica sand, quartz powder (optional), and superplasticizer with water cement ratio (w/c) 0.15 to 0.17. The silica fume and superplasticizer have an important role in RPC compressive strength. The silica fume will produce secondary hydrates by pozzolanic reaction with the lime resulting from primary hydration (cement hydration), then it makes a denser concrete matrix. Commonly the silica fume/cement optimum ratio used for RPC is 0.25. Meanwhile, the use of very low w/c enhance highest compressive strength, but low in workability of RPC fresh mix. For that reason, the superplasticizer is added to the mix to improve the workability (Richard & Cheyrezy, 1995). According to Wille, *et al.*, 2011, the superplasticizer optimum dosage is 1.4% to 2.4% of cement weight.

The original RPC 200 consumes cement about 800 kg/m^3 to 1000 kg/m^3 which involves some problems such as a high temperature of hydration, caused shrinkage, and also expensive on production cost. To eliminate these problems, applying a pozzolanic material in RPC mixture shows a potential solution (Yazici, Yardimci, Yiğiter, Aydin, & Türkel, 2010).

In terms to produce an inexpensive cost of RPC, Yu, Spiesz, and Brouwers, 2014, were studied to develop modified RPC (UHPC) mixture with efficient cement and mineral admixtures use. There were two types of sand used, one was a normal sand with the fraction 0-2 mm and the other one was a micro-sand with the fraction 0-1 mm. The fraction of these sand is different with the fraction of sand that used in original RPC (600 µm maximum). Limestone and quartz powder were used as fillers to replace cement. Furthermore, they reported the results showed that non-fiber UHPC only about 650 kg/m^3 of binders used, the compressive strength reach around 88 MPa at 28 days with standard curing.

As its application to the concrete mixtures, silica fume is a costly material that imported from overseas to the Indonesian construction industry, contributes resulting in increased cost of the final product of concretes. Using supplementary cementitious materials that processed from the agricultural wastes are an alternative for the developed country like Indonesia to minimize cost in concrete production. Tuan et al., 2011; Tuan, Ye, Breugel, Fraaij, et al. 2011; and Van et al., 2014, reported that rice husk ash (RHA) is suitable for use as a supplementary material to make UHPC. Rajasekar et al., 2018, they research results proved that up to 20% substitution of sugarcane bagasse ash (SCBA) is good enough for producing UHSC. While, Wi et al. 2018, found that the utilization of nano palm oil fuel ash (nPOFA) is an increase in compressive strength of mortar specimens.

The present research is an initial study of the use of bamboo leaf ash as silica fume substitution to produce RPC with local Indonesian material. In this experimental, the mixture composition of RPC used is based on previously study of Richard and Cheyrezy 1995; Wille, Naman, and Parra-Montesinos 2011, and Yu, Spiesz, and Brouwers, 2014.

BAMBOO LEAF ASH

Bamboo is one of the oldest building materials used by the human being. It has been widely used for household appliances, furniture products, and extended to industrial applications. The processing of bamboo generates large volumes of leaf wastes, which are deposited in landfills or burned in the open air, caused negative effects in the environment.

The studies on using bamboo leaf ash (BLA) as supplementary cementing materials are still rare. Dwivedi, Singh, Das, & Singh, 2006, reported that bamboo leaf burned in the open atmosphere and then incinerate at 600 ^{O}C for 2 hours in a furnace derive 75.9% of amorphous silica by weight of ash. The experimental result also shows that BLA is a good reactivity pozzolanic material. Table 1 present the main chemical elements in BLA from previously work of some researcher.

Table 1. Main chemical composition of bamboo leaf ash

Main elemen	Composition (weight %)		
	(Dwivedi et al., 2006)	(Villar-Cociña, Morales, Santos, Savastano, & Frías, 2011)	(Dhinakaran & Chandana, 2016)
SiO_2	75.90	80.4	80.27
Al_2O_3	4.13	0.71	1.99
CaO	7.47	5.06	6.00
Fe_2O_3	1.22	0.71	1.92
MgO	1.85	0.99	1.73
Na_2O	0.21	0.08	0.26
K_2O	5.62	1.33	3.05
LoI	-	8.04	-

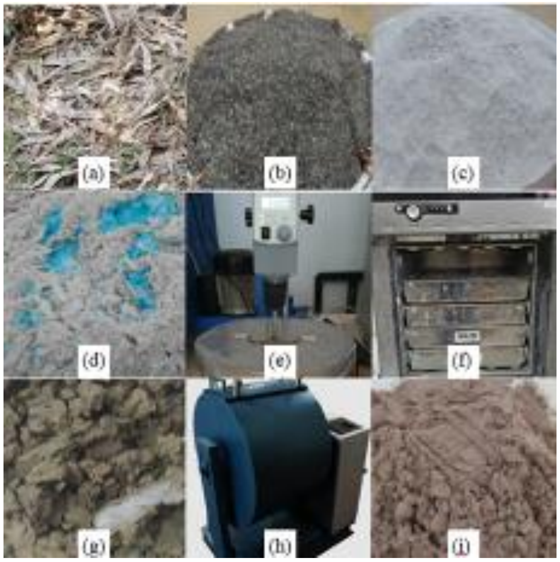
MATERIAL

Type I ordinary Portland cement confirms to ASTM C 150, was used in this study. The silica sand (75 µm - 600 µm) used for the mixes were obtained from Lhok Nga, Aceh Besar, Aceh Province. Water from the reserved osmosis process was used for the mixing. The admixtures such as SikaFume®, a extremely fine latently silica fume (SF), and Sika® ViscoCrete®-8045 P, a modified polycarboxylate super-plasticizer (SP), were both supplied by PT. Sika Indonesia. Flake sodium hydroxide were used in fusion process to form BLA from Spiny Bamboo (*Bambusa blumeana*) leaf.

METHOD

Preparation of bamboo leaf

Fallen dry of Spiny bamboo leaves collected from around main campus of Universitas Malikussaleh, Reuleut, Aceh Utara, Aceh Province, were burning in the open atmosphere. The black ashes resulted from burning were calcining in a laboratory electric furnace at 680 °C temperature for 1.5 hours. Then, the ashes were ground and sieved below 1.68 mm. These bamboo leaf ash showed a white grayish color (Fig. 1c) were used for further synthesizing process. In this study the synthesizing process of ash was conducted with the method that clearly states by Chang and Shih, 1998. Finally, the ashes appeared in light brown after synthesizing process with fine powder particle sizes (Fig. 1i).



(a) Dry Spiny bamboo leaves
(b) Burning in open atmosphere
(c) Calcining in furnace
(d) Combusting with NaOH in furnace
(e) Stirring in water
(f) Incubating in oven
(g) SBLA gel drying in oven
(h) Grinding in Los Angeles abrasion machine
(i) SBLA powder
Fig. 1 Preparation of bamboo leaf

Mix design of RPC

In the present study, the initial experiment designed to obtain RPC mixture design as below:

(1) A maximum binder content of 640 kg/m^3 adopted according to the study of Yu, Spiesz, and Brouwers, 2014.
(2) The ratio of water/binder (w/b) and superplasticizer/binder ratio (SP/b) using 0.19 and 0.24 respectively as a suggestion of Wille, Naman, and Parra-Montesinos 2011.
(3) A maximum particle size of silica sand of 0.6 mm used as same as Richard and Cheyrezy 1995
(4) The optimum fine powder admixture added to the mixture by 25% of the weight of cement that accordance with Richard and Cheyrezy 1995; and Wille, Naman, and Parra-Montesinos 2011.
(5) Common technologies adopted for the preparation of RPC, which include mixing of fresh concrete with a planetary mixer, pouring and compaction by vibrating and curing at room temperature.

Base on the above provisions and using of the absolute volume method, the developed RPC mixtures are listed in Table 2.

Table 2. Mixture composition of reactive powder concrete

#	Material	Spesific grafity (kg/m^3)	Weigth (kg/m^3)	
			RPC 1	RPC 2
1	Cement	3130	636,30	636,30
2	Silica sand	2709	1485,00	1485,00
3	Silica fume	2200	151,30	-
4	Synthesized BLA	2200	-	151,30
5	Water	1000	154,50	154,50
6	Superplasticizer	1060	19,00	19,00

Mixing procedures

According to the following procedures, as shown in Table 3, all materials of RPC were mixed using a planetary mixer.

Table 3. Mixing procedures

#	Processes	Duration (minutes)	Stir speed (rpm)
1	All dry material (cement, sand, and admixture powder) start to mixing	3	2 (95)
2	Dry mix + 30% water	2	2 (95)
3	Added 30% water + 50% SP	2	2 (95)
4	Added 30% water + 50% SP	2	2 (95)
5	Finally, added 10% water	3	4 (135)
Total		12 minutes	

Workability and compressive strength test

Immediately after mixing, the workability of the RPC fresh mixture was tested according to ASTM C 1437. The fresh mixture was filled into the conical mold and placed on the electric flow table. Shortly, the cone was lifted up then the table drops 25 times. Two perpendicular diameters to each other were measured. The average of two measured was recorded as the flow-ability value of the fresh mix.

The cube molds 70.7 mm x 70.7 mm x 70.7 mm were used to pour fresh concrete after the workability test, then compacted using an electric vibrating table for 3 minutes. After 24 hours, the specimens were remolded and immersed in room temperature. The compressive strength test was carried out at the age of 14 days and 28 days of the specimen. The average strength of specimens was determined from three cubes tested at each age.

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RESULTS AND DISCUSSIONS

Workability of RPC fresh mix

The workability of mortar flow known by flow table test which also can be applicable for RPC. The slump flow of fresh RPC mixes is presented in Fig. 2.

(a) RPC 1 (b) RPC 2
Fig. 2 Slump flow of RPC mixes

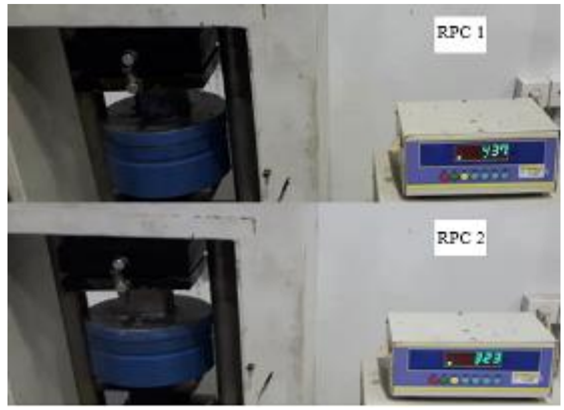
The average slump flow of fresh RPC 1 as control mix was 205 mm, whereas when SF changed with SBLA in RPC 2 mix, the average slump flow increased to about 221 mm or 7.8%. These values conformity with Ahmad, Hakeem, & Maslehuddin, 2014, which the result of the slump flow ranges from 180 mm – 220 mm.. Hence, this initial experiment pointed out that SBLA contributes towards a better to the performance flow of RPC.

Compressive strength

The average compressive strength test results for 14 and 28 days of all mixtures are presented in Table 4. In these results at 28 days compressive strength test, the peak loading was 437 and 323 kN for RPC 1 and RPC 2 respectively as shown in Fig. 3

Table 4. RPC Compressive strength

#	Mix	Compressive Strength (MPa)		Standard Deviation	Age (days)
		Specimen	Mean		
1	RPC 1	78,4	77,33	1,51	14
2		78,0			
3		75,6			
4		85,6	86,50	0,90	28
5		87,4			
6		86,4			
1	RPC 2	57,2	56,40	0,80	14
2		56,4			
3		55,6			
4		64,6	63,87	0,70	28
5		63,8			
6		63,2			



.Fig. 3 Peak loading of RPC 1 and RPC 2

At the age of 14 days, the compressive strength of the two types of RPC reached 75.60 MPa (RPC 1) and 55.60 MPa (RPC 2), about 87.40% and 87.05% of compressive strength at 28 days. The RPC mixture containing 25% SBLA of cement mass has lower compressive strength compared to the RPC mixture containing 25% SF. However, the RPC 2 mixture was able to maintain a 73.84% compressive strength of RPC 1 under normal curing conditions. The use of SBLA with 25% of the mass of cement in this initial experiment is good enough to substitute the SF in the RPC. So, SBLA is promising to be used as an alternative pozzolanic material to producing RPC. On the other hand, the compressive strength of RPC 1 was almost the same as that of results of Yu, Spiesz, and Brouwers, 2014, which shows that local material can be used in the RPC mix design with low cement content.

By comparing the research results of Tuan, Ye, Breugel, Fraaij, et al., 2011, which uses 20% agricultural waste (rice husk ash) by cement mass results in the highest compressive strength of UHPC, so in further research can be developed the use of SBLA less than 25% of cement mass and with different curing regime to achieve more satisfying results.

CONCLUSIONS

The results show that SBLA is satisfactory for use as a pozzolanic material to produce RPC. It is possible to use local material and low cement content to produce RPC mixture with compressive strength up to 86 MPa which used immersed curing in room temperature.

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