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STRENGTH ENHANCEMENT BY COMBINED THE CALCINED WATER SUPPLY SLUDGE IN BAGASSE ASH GEOPOLYMER CONCRETE

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ABSTRACT

Geopolymer concrete has been introduced as a green construction material as the Portland cement production involves a large amount of natural material and energy. The well-known sources materials to produce geopolymer concrete is a pozzolanic material and also a non-valuable or waste from the industrial production. This study, bagasse ash (BA) was the main constituent, which contained very high silica content. The calcined water supply sludge (CWS) was incorporated to the mixture as it contained substantial amount of alumina. The geopolymer concretes were cast by using 10 molars of NaOH and the $NaOH/Na_2SiO_3$ ratio of 1.0. The BA with partial replacement by CWS at 0-7.5% by weight, the alkaline solution to binder (AL/B) ratios in the range of 0.50-0.60, and the curing temperature between 40-100ºC were investigated. It found that the using CWS enhanced the workability of fresh mixtures and assisted the compressive strength of bagasse ash geopolymer concrete reached 40 MPa at 90 days. The low alkaline to binder ratio (AL/B) and high temperature of curing also encouraged the compressive strength of geopolymer concrete. However, the curing at 40ºC still provided the usable range of compressive strength. This is an opportunity to utilization worthless waste as construction materials and reduces the environmental impact.

Keywords: geopolymer concrete, bagasse ash, water supply sludge, waste materials.

INTRODUCTION

The greenhouse gas problem has a direct impact on the current global environment. It is mainly the result of gases produced by combustion in industrial processes. About 7% of the total CO_2 is generated by the cement industry and release to the atmosphere [1]. The Portland cement is the main material used in the construction industry and more than 4100 million metric tons were used in 2017 [2]. Many researchers have thus concentrated on the use of alternative cement to supplement the use of ordinary Portland cement (OPC). The new binder called ‘geopolymer’ has been introduced for making concrete. It undergoes setting and hardening and possesses properties similar to OPC concrete. The main ingredients or source materials to produce geopolymer are materials rich in silica and alumina such as fly ash, slag and metakaolin. Fly ash is one of the preferred source materials for reasons of availability, and good properties. The fly ash is a pozzolanic material with a primarily alumino-silicate, and amorphous or a semi-crystalline structure. It is quite reactive and thus readily reacts with the highly alkaline solutions [3] in the geopolymer reaction system. Fly ash is now becoming a valuable commodity due to its common use to partially replace OPC in concrete mixture [4, 5]. Bagasse ash (BA) from the sugar mill industries is a class N pozzolanic material [6] and a large amount is generated and disposed of throughout the country. The utilization of BA is much less than that of fly ash. The fact that the BA is widely available, and the cost is low, so it is thus a challenge to use it as a source material in the production of geopolymer concrete [7,8]. Moreover, the reused BA decrease carbonaceous matter and silicate minerals that are mostly BA composition and have a potential to be health hazard including have many negative impacts on environment. The carbonaceous material was particle matter (PM) because of the ultra–fine grain size which can be inhaled deep into the alveolar region of the lung. Crystalline silica form in BA re-suspends respirable-size particulate and associates with a respiratory disease. By the inhaled silica particle interacts with alveolar macrophage and the consequences of silica induced cellular toxicity finally cell death ([9]-[12]). According to Thailand, the one in two majority of the residual burning or BA comes from sugarcane and accounts for PM10 (54.2%) and PM2.5 (39.5%) emission of air pollutants [13, 14]. Thus, the best possible solution for BA reduction is concrete replacement. However, the source material for geopolymer must contain both silica and alumina [15]. As BA contains high silica and very low alumina contents [16]. Therefore, additional alumina is required for the geopolymerization [17].

In the water supply production, alum or an ammonium aluminum sulfate ($NH_4Al(SO_4)_2{\cdot}12H_2O$) is used to help with sedimentation. The residual from the process is a water supply sludge (WS). Some WS has been used in fired clay brick production and as additive to improve the impermeability of soil. However, a large amount is disposed as landfill. The cost of WS is also low, and research has been conducted to use it as supplementary cementitious material [18]. The WS contains a significant amount of alumina [19] and its use should enhance the properties of geopolymer concrete.

In this work, BA and calcined water supply sludge (CWS) were used as source materials to produce geopolymer concretes. They were tested to meet the goal of producing satisfactory concretes. This work should

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provide guidelines to use such industrial wastes and reduce the OPC consumption.

EXPERIMENTAL PART

Raw materials, BA were collected from a landfill site in a sugar mill plant and the impurities were removed. WS was from the regional waterworks plant. It was sun dried and calcined at 600ºC for 2 hours. Both, BA and CWS were ground by ball mill until their particle sizes retained on the sieve No. 325 were less than 5%. The 10 M sodium hydroxide (NH), sodium silicate (NS) with 28.65%SiO_2 and 9.77%Na_2O_3, NH:NS ratio of 1.0, three alkaline solutions to binder (AL/B) ratios of 0.50, 0.55 and 0.60 were used. River sand with fineness modulus of 2.6 and limestone coarse aggregates with a nominal size of 3/8" were used.

Mix design and testing, the mix proportions of geopolymer concrete are shown in Tables 1 and 2. The workability of concretes in terms of the slump was tested in accordance with ASTM C143 [20]. The geopolymer concrete samples were cast and placed in a controlled 25ºC room for a delay time of 60 minutes ([21]-[23]). Then, the samples were cured at 40, 60, 80, and 100ºC for 48 hours. After curing, the samples were de-molded and stored in a controlled 25ºC until the testing age. The setting time of geopolymer paste and compressive strength were tested.

Table-1. Mix proportion of geopolymer concrete with CWS cured at 60ºC (kg/m^3).

Mix No.	Designation	BA	CWS	NH/NS	Aggregate	
					Fine	Coarse
1	0.60CWS7.5	379	31	123	561	1208
2	0.55CWS7.5	379	31	113	564	1215
3	0.50CWS7.5	379	31	103	567	1221
4	0.60CWS5.0	379	31	123	561	1208
5	0.55CWS5.0	379	31	113	564	1215
6	0.50CWS5.0	379	31	103	567	1221
7	0.60C	410	-	123	561	1208
8	0.55C	410	-	113	564	1215
9	0.50C	410	-	103	567	1221

where:
BA isbagasse ash.
CWS is calcined water sludge.
C is control.

Table-2. Mix proportion of geopolymer concrete cured at 40, 60, 80 and100ºC (kg/m^3).

Mix No.	Designation	Temp ºC	BA	CWS	NH/ NS	Aggregate	
						Fine	Coarse
1	0.60CWS7.5	100	379	31	123	561	1208
2	0.55CWS7.5	100	379	31	113	564	1215
3	0.50CWS7.5	100	379	31	103	567	1221
4	0.60CWS7.5	80	379	31	123	561	1208
5	0.55CWS7.5	80	379	31	113	564	1215
6	0.50CWS7.5	80	379	31	103	567	1221
7	0.60CWS7.5	60	379	31	123	561	1208
8	0.55CWS7.5	60	379	31	113	564	1215
9	0.50CWS7.5	60	379	31	103	567	1221
10	0.60CWS7.5	40	379	31	123	561	1208
11	0.55CWS7.5	40	379	31	113	564	1215
12	0.50CWS7.5	40	379	31	103	567	1221

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Table-3. The chemical compositions of BA and CWS determined by XRF.

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SiO_3	LOI
BA	77.57	4.15	3.00	3.72	3.08	0.80	11.94
CWS	45.50	27.37	11.85	1.81	3.56	0.71	-

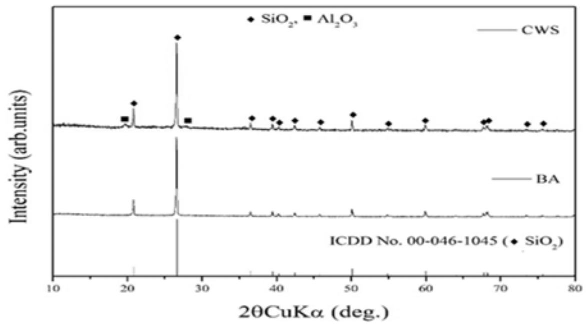

Figure-1. XRD of BA and CWS.

RESULTS AND DISCUSSIONS

Characterization of Raw Materials, the chemical compositions of BA and CWS were obtained from the XRF analysis and shown in Table-3. The BA contained a high SiO_2 of 77.57 % but a low Al_2O_3 of only 4.15%. The loss on ignition (LOI) was relatively high at 11.94% indicating that the burning of BA was not complete [24]. The high amount of LOI in bagasse ash could adversely affect the strength of concrete [25,26]. The CWS, on the other hand, contained a significant amount of Al_2O_3 of 27.37 %. With the amount of $SiO_2+Al_2O_3+Fe_2O_3$ of 84.72%, the CWS could be classified as pozzolan class N according to ASTM C618 [6]. The absent of LOI in CWS was due to the calcination at 600ºC for 2 hours [27]. The XRD patterns as shown in Figure-1, indicated that the BA and CWS had a semi-crystalline amorphous structure with distinctive peaks of quartz at 27º 2θ [28]. From the results of SEM as shown in Figure-2, the BA particles were angular and irregular in shapes which is in line with the previously reported results [29]. Figure-3 showed that the CWS particles were sub-rounded to irregular. The slightly rounded CWS particles could assist the workability of the fresh mixture. It has been reported that the solid spherical particle of fly ash with smooth surface increased the workability of pozzolan concrete [30].

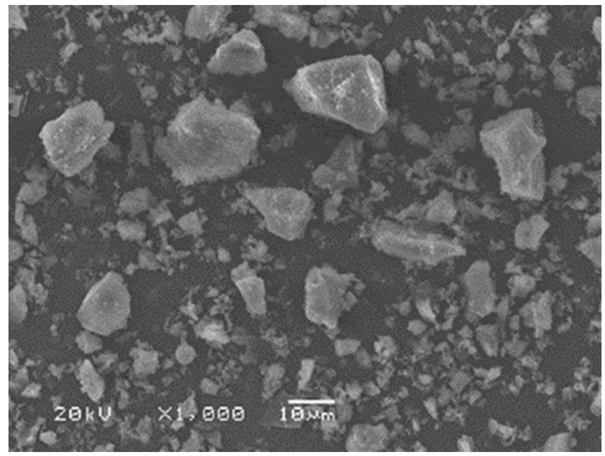

Figure-2. Morphology of BA.

Effect of Replacement CWS, the effect of replacing the bagasse ash with CWS Figure-4, shows that the compressive strength of the samples increased with an increased percentage of displacement and decreased when the 5% displacement rate was exceeded at 3, 7, and 28 days of testing. In addition, 7.5% replacement of CWS was found to provide maximum compressive strength at 90 days. Therefore, replacement intervals were selected in this study at 5% and 7.5% ratios for optimal replacement.

Workability of Geopolymer Concrete, the results of slump of fresh geopolymer concrete as shown in Figure-5, indicated that the increase in AL/B ratio resulted in the increase in the slump values of the geopolymer concrete. The slump of control mixture (CWS = 0%) at AL/B ratio = 0.50 was 15 mm which was higher than that of the geopolymer concrete with CWS. With increasing AL/B ratio, the slump of geopolymer concrete with CWS increased. At high AL/B ratio of 0.60, the slumps of the geopolymer concretes with CWS were higher than that of the control mixture. The workability of geopolymer concrete also increased with amount of CWS. At AL/B ratio = 0.60, the slumps were 38, 55 and 68 mm for geopolymer concrete with 0, 5.0 and 7.5% CWS, respectively. The CWS improved the workability of the mix because it contained a good portion of round particles [31].

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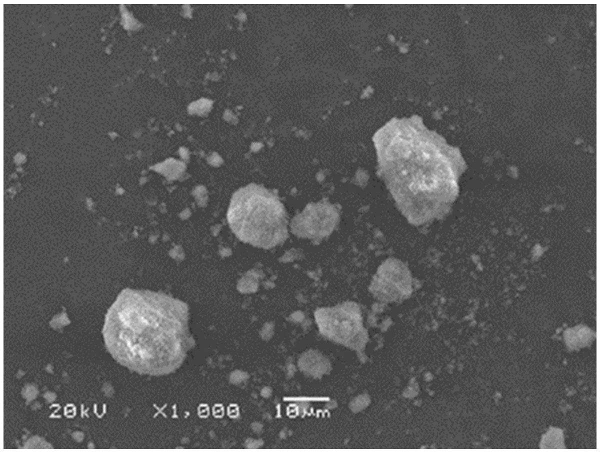

Figure-3. Morphology of CWS.

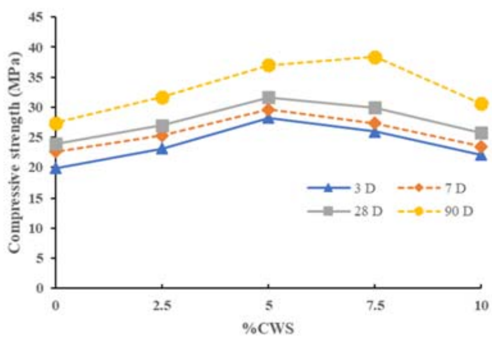

Figure-4. The effect of replacement of CWS on compressive strength.

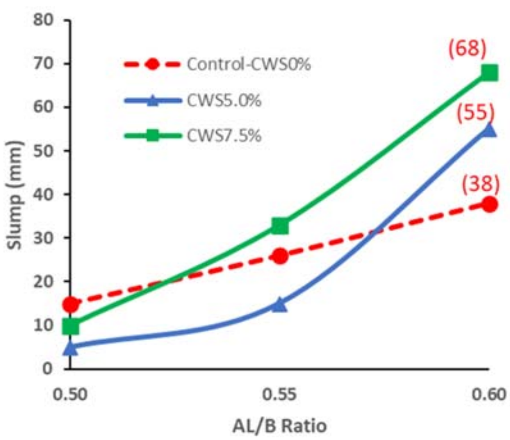

Figure-5. Workability of geopolymer concrete with various CWS contents.

Setting Time of Geopolymer Paste, Figure-6, presents the setting time of geopolymer paste in this research. The initial setting time of control geopolymer paste was 172 minutes and the final setting time was 210 minutes. The replacement of BA with CWS resulted in the increase in setting time of geopolymer paste. For the pastes with 5.0 and 7.5%CWS, the initial setting times increased to 205 and 225 minutes; and the final setting times were delayed further to 240 and 252 minutes, respectively. The relatively long setting times with these mixtures are beneficial for normal use in construction. It was reported that the incorporation of CWS in concrete delay the setting and hardening of concrete due to the presence of high content of SO_3 and P_2O_5 [32]. In this case, the P_2O_5 was not detected and the delay was due to the presence of SO_3.

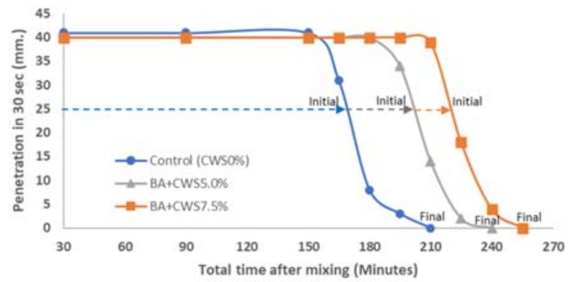

Figure-6. Time of setting of geopolymer with 0-7.5% CWS cured at 60ºC.

Compressive Strength, the compressive strength of geopolymer concrete cured at 60ºC for 48 hours as shown in Figure-7, varied between 15.0-40.0 MPa and increased with age similar to that observed in OPC concrete [33]. For the low slump mixture, good compaction was needed; otherwise unintentional pore was present in the structure [3]. AL/B Ratio, Table-4 Shows the compressive strength of geopolymer concrete was affected by the AL/B ratio. The low AL/B ratio tended to produce concrete with higher compressive strength [35]. In the case of AL/B ratio = 0.50, the 90-day compressive strength of control geopolymer concrete was 27.37 MPa. With the AL/B ratio of 0.60, the compressive strength was lower to 21.64 MPa. Similar result of lowering of strength was reported for fly ash geopolymer concrete [36]. Even though the low AL/B ratio was expected to give a high compressive strength concrete, the compaction needed to be sufficient as the workability was low due to the less amount of solution in the mixture. At 5.0% CWS, the highest compressive strength was obtained with concrete with AL/B ratio = 0.60. While the use of 7.5% CWS also provided the highest strength with the ratio of AL/B ratios of 0.50 and 0.55.The highest compressive strength was 38.4 MPa (AL/B = 0.50, CWS = 7.5%), which was about 40% higher than that of geopolymer concrete containing only BA. An improvement of properties due to the incorporation of CWS could be attributed to a number of factors, such as the increase of alumina oxide content, the improvement of workability through the particle lubricating action and the filler effect [37].

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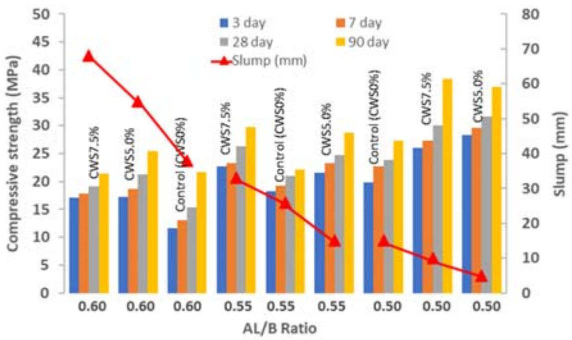

Figure-7. Compressive strengths of geopolymer concretes with 0-7.5% CWS cured at 60ºC.

Curing Temperature, sTable-5 Shows the compressive strength of geopolymer concrete containing BA and 7.5% CWS. Heat curing was varied between 40-100ºC for 48 hours [38], then cured at ambient temperature until the testing ages at 3, 7, 28 and 90 days. The result showed that compressive strength of geopolymer concrete rapidly increased within 3 days. After that, the strength increased slightly with age. The strength development of geopolymer concrete and OPC concrete were similar. The result also strongly indicated that the temperature of curing directly affected the strength of geopolymer concrete. Considering, geopolymer concrete mixture of 0.50CWS7.5 (AL/B = 0.50, CWS = 7.5%), the compressive strengths were 30.0 and 49.4 MPa for the curing temperature of 40 and 100ºC, respectively. The strength improvement was more than 50%. Therefore, the curing in high temperature chamber provides a good mechanism for the reaction of the geopolymer [39, 40]. However, high temperature curing process is difficult for normal concrete structure. The temperature curing is suitable for pre-cast concrete members and the moderate temperature should be considered to lower the cost of energy. Therefore, appropriate compressive strength of geopolymer concrete should be used where the low curing temperature could be achieved.

Table-4. Compressive strength of bagasse ash geopolymer concrete with various replacement of CWS.

Mix No.	Designation	Temp ºC	Compressive strength (MPa)			
			3 D	7 D	28 D	90 D
1	0.60CWS7.5	60	17.08	17.86	19.06	21.33
2	0.55CWS7.5	60	22.72	23.28	26.31	29.70
3	0.50CWS7.5	60	25.94	27.34	29.98	38.38
4	0.60CWS5.0	60	17.26	18.66	21.32	25.41
5	0.55CWS5.0	60	21.49	23.20	24.67	28.81
6	0.50CWS5.0	60	28.27	29.64	31.68	37.02
7	0.60C	60	11.66	13.06	15.31	21.64
8	0.55C	60	18.17	19.22	20.95	22.09
9	0.50C	60	19.87	22.64	23.91	27.37

Table-5. Compressive strength of geopolymer concrete with various temperature.

Mix No.	Designation	Temp °C	Compressive strength (MPa)			
			3 D	7 D	28 D	90 D
1	0.60CWS7.5	100	40.97	36.19	36.83	38.72
2	0.55CWS7.5	100	41.39	38.65	39.12	40.51
3	0.50CWS7.5	100	42.37	38.37	43.83	49.41
4	0.60CWS7.5	80	25.01	23.19	24.43	25.13
5	0.55CWS7.5	80	27.19	26.88	27.67	29.90
6	0.50CWS7.5	80	28.16	26.31	27.71	31.81
7	0.60CWS7.5	60	18.86	19.11	21.54	24.37
8	0.55CWS7.5	60	23.92	25.30	26.87	31.52
9	0.50CWS7.5	60	27.28	29.01	30.63	35.43
10	0.60CWS7.5	40	14.21	14.66	17.02	23.53
11	0.55CWS7.5	40	16.62	17.41	19.37	26.02
12	0.50CWS7.5	40	17.05	17.53	22.92	30.03

CONCLUSIONS

Based on the information obtained, the conclusions were as follows:

Waste materials viz., bagasse ash and water supply sludge could be used as the source materials for making geo polymer concrete with satisfactory compressive strength of 40 MPa.

The delay in setting time was due to the presence of SO_3 and the improvement in workability was due to the large number of rounded particles of calcined water supply sludge. The improved workability enabled the use of low alkali to binder ratio to obtain high compressive strength.
The replacements of bagasse ash with 5.0 and 7.5% calcined water supply sludges were effective with the delay in setting time, and improvements in workability and compressive strength of geo polymer concrete.

From the results of the research. It was found to be able to improve the properties of concrete geo polymers produced from bagasse ash. This knowledge to be further developed and will lead to the disposal of materials that are hazardous to health and positively affect the environment.

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AUTHOR'S NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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