Strength Performance of Sustainable Mortar Containing Recycle Sewage Sludge Ash (SSA)

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ABSTRACT

Sewage sludge is a by-product generated within the wastewater treatment process. Severe concern arised as the sludge are massively been dumped to the landfill and it may affect the environment. Many studies had been conducted in reusing the sewage sludge as construction material, where it is one of the optional ways to solve the issue. In this study, dried sewage sludge was incinerated with two different temperatures in order to produce sewage sludge ash (SSA), which are 800°C and 1000°C. After few processes, this SSA then reused in mortar as cement replacement with the replacement percentage of 5%, 10%, 15% and 20% by weight. The strength performance of mortar specimens was investigated after 7, 28, 60 and 90 days of curing. From the results, it is clearly showed that the compressive strength of all mortar specimens increased when the period of curing was prolonged. Moreover, almost all compressive strength of SSA mortars was higher than the control mortar. Therefore, there is potential to reuse this waste material as part of construction materials and hence, its plays an important role for future researches in minimisation of waste.

Keywords: *sewage sludge, sewage sludge ash, recycle, compressive strength, mortar*

INTRODUCTION

The problem regarding the waste generated had always been discussed globally since decades ago. This issue will be a crisis if a huge production of waste generated every day is not been taken care of. Wastewater from residential area, hospital, commercial, industrial establishments, and rain water are also considered as a waste [1]. The wastewater from the sewerage system is channelled to the wastewater treatment plant, where it will be treated with several processes before it can be released to the environment. At this point, the concern issue appears regarding the sewage sludge generated from the wastewater treatment process. Over the year, this semisolid by-product is massively being dumped into the landfill [2]. In Malaysia alone, it was reported that about 5.3 million m^3 sewage sludge was produced annually [3]. Without a proper disposal method, this might create various negative impacts to the environment. Hence, it is a vital to seek out an alternative root for the disposal method of sewage sludge, rather than be ended up at the landfill.

The global focus on sustainability and green technology approaches, somehow had affected the construction and cement industry. In 2013, it is reported that the world cement production had contributed roughly 9.5% of global CO_2 emission [4]. This justification had led to the numerous studies to search for the solution regarding this matter, which is part of it had shown an interest of reusing the waste or by-product as part of construction materials. It is fascinating that previous studies found that the sewage sludge had a potential to be reused in producing building and construction materials, as well as enhancing certain properties of conventional construction materials. The dried sewage sludge and sewage sludge ash (SSA) had been investigated to produce brick [5-6], lightweight aggregates [7-8], paver block [9], tiles [10], as cement substitution material for mortar and concrete [11-13], also as raw materials in cement blended production [14].

From the literatures, there were ranges of temperature used in incineration process from 550°C to 1200°C, in order to convert the dried sewage sludge into ashes form [11-15]. Tantawy *et al.* [1] stated that by using 800°C, it will help to preserve the pozzolanic value of the SSA, while finding by Tay and Show [16], showed that using SSA incinerated at 1000°C had given the highest strength of mortar at 28 days of curing. As significant findings found through the literatures, this present study had been initiated to investigate the potential of local sewage sludge to be used as partial cement replacement in making mortar. Two temperatures to calcine the sludge, 800°C and 1000°C were adopted in the incineration process to form SSA.

METHODOLOGY

Preparation of Materials

Sewage sludge cake was collected from Indah Water (IWK) wastewater treatment plant at KLIA Sepang, Malaysia. The sewage sludge cake was then dried under the hot sun during the day time for about three to five days. This process needed in order to remove 70% to 90% of its moisture content. The dried sewage sludge then underwent controlled incineration to obtain the ashes and also to remove the organic matter content. Gas kiln furnace was used to conduct this incineration process, with temperature of 800°C and 1000°C; and it is burned for five hours. To get more fine powder of SSA, Ball Mill (Two Tier Jar) was used to ground sewage sludge ash (SSA) with 30 rpm for eight hours. All these processes are as shown in Figure 1. Figure 2 shows the particle of SSA after incineration and grinding process. XRF PANalytical was used to carry out the chemical composition analyses of SSA. Mining sand with the fineness modulus of 3.45 was used in this study. The grading of the fine aggregate was conducted according to ASTM C144-11 with sieve size between 0.063 mm to 5 mm. Type I Portland cement locally made was used in this present study.

The mix proportion ratio of 1:3 was used in this study, where it indicates one portion of cement was mixed with three portions of fine aggregate. The water cement ratio is taken as 0.5. For each temperature burning of SSA (800°C and 1000°C), four batches of SSA mortar mix with different percentages of SSA replacing cement were prepared. The percentages of SSA replacing cement by weight are 5%, 10%, 15% and 20%. These mortar specimens were cast in 50 mm x 50 mm x 50 mm cube mortar moulds. Without adding any SSA in the mix proportion, one batch of normal mortar was prepared as control. All mortar specimens were demoulded after

24-hours of casting and cured under water curing condition. All specimens were tested for compressive strength at the age of 7, 28, 60 and 90 days.

Testing Specimen

Compressive strength test of hardened mortar was conducted according to ASTM C109-13 [17]. The loading pace rate of 0.9 kN/s was applied. The data obtained from the testing was recorded to the nearest 0.05 N/mm^2, while the average result was rounded off to the nearest 0.1 N/mm^2. The compressive strength was calculated as given in Equation (1).

$$fm = P/A \qquad (1)$$

where:

fm = compressive strength (MPa or N/mm^2)
P = total maximum load (N)
A = area of loaded surface (mm^2)

Figure 1: Processes to Convert the Sewage Sludge Cake to Sewage Sludge Ash (SSA)

a) b)

Figure 2: a) Sewage Sludge Ash After Incineration Process; and b) Fine Sewage Sludge Ash (SSA) After Grinding Process

RESULTS AND DISCUSSION

Chemical Composition

The results from the XRF analysis are shown in Table 1. It presents the chemical composition of SSA incinerated at the temperature of 800°C and 1000°C, as compared to the Portland cement. Monzó *et al.* [18], enlighten that the chemical properties of sewage sludge differ from one another, depending on the origin of the wastewater and also the process conducted within the treatment plant. It is clearly shown that the four major compounds in both types of SSA (SiO_2, $Al2O_3$, $Fe2O_3$ and CaO), were also detected same as in the Portland cement. It was noticed that the SiO_2 and CaO oxides that found in the SSA affect the strength of mortar specimens [14]. Both SSA can be classified as Class C pozzolan material since it satisfies the standard requirement stipulated in ASTM C618-12a [19]. Therefore, these SSAs have the potential to be used as partial replacement for Portland cement in making mortar.

Table 1: Chemical Composition of Portland Cement, SSA Calcinated at 800°C and 1000°C (Mass in %)

Composition	Portland Cement	SSA 800˚C	SSA 1000˚C
SiO_2	14.2	34.2	35.3
$Al2O_3$	3.16	18.4	19.3
$Fe2O_3$	3.30	7.36	7.56
CaO	55.8	4.17	4.10
MgO	0.99	1.62	1.72
Na_2O	0.11	0.26	0.32
K_2O	0.53	2.08	2.15
Na_2O	0.11	0.26	0.32
K_2O	0.53	2.08	2.15
P_2O_5	0.04	8.97	9.31
SO_3	4.03	3.64	3.31
TiO_2	0.16	0.83	-
Others	0.33	0.65	-

Compressive Strength

Figure 3 demonstrates the compressive strength of SSA mortar (SSA incinerated at 800°C) and control mortar at the age of 7, 28, 60 and 90 days. It is clearly shown that all the mortar specimens experienced an increase in strength with respect to the increment of curing ages. At day 7 of age, nearly all the SSA mortar specimens exhibit highes compressive strength coressponding to control specimen which is 48.85 MPa, 49.91 MPa, and 43.64 MPa for those taht contained 5%, 10% and 20% replacement level of SSA (incinerated at 800°C) respectively. While for the SSA800 15%, the compressive strength recorded is 41.07MPa, where it is slightly lower as compared to the normal specimens which recorded 42.38 MPa. However, as the age of curing increases, all SSA mortar specimens showed significant increase in compressive strength and it is much higher as compared to the normal mortar specimen. This can verify that the presence of SSA may assist the hydration process within the hardened specimens which had enhanced the strength development of the specimens at the longer hydration time.

Within the limited study, it was found that the compressive strength of mortarmade of SSA incinerated at 800°C, exceeded of control mortar. The mortar with 15% of replacement recorded higher compressive strength at 90 days of age, which marked 75.68 MPa. It was noted that the SSA mortar specimen with 5% and 15% replacement showed high strength among all.

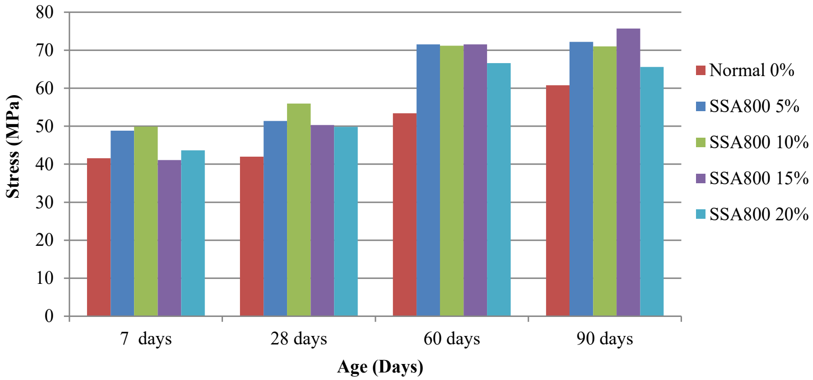

Figure 3: Compressive Strength of SSA Mortar which the Sludge was Incinerated at 800°C

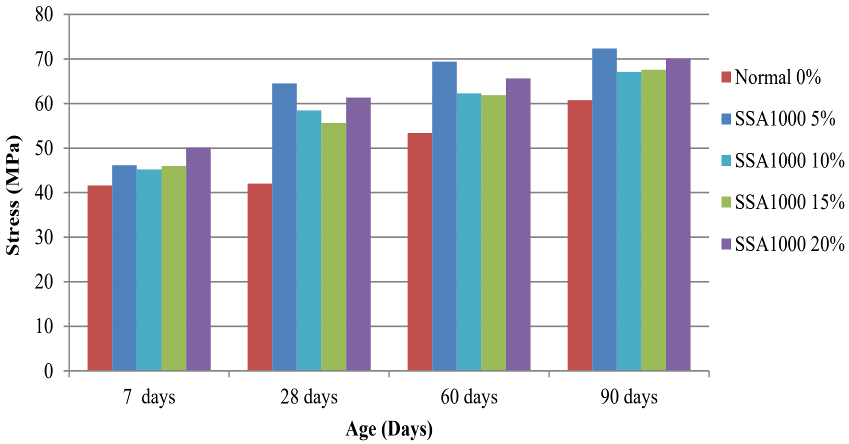

Figure 4: Compressive Strength of SSA Mortar which the Sludge was Incinerated at 1000°C

The compressive strength of SSA mortar which the sludge was incinerated at 1000°C compared to control mortar at the age of 7, 28, 60 and 90 days, is illustrated in Figure 4. The results showed that all SSA mortar specimens increased in compressive strength as compared with that of control mortar. The SSA mortar with 5% and 20% replacement level of SSA, showed a good strength development as the age of curing increased. Respectively, the compressive strength for SSA mortars at 90 days are 72.35 MPa for those containing 5% (SSA1000 5%), and 70.13 MPa for those containing 10% (SSA1000 20%) which are the highest strength achieved as compared to other series of mortar specimens. From this result, it is suggested that the SSA obtained from the incineration at 1000°C can partially replaced cement up to 20% to enhance the strength of mortar.

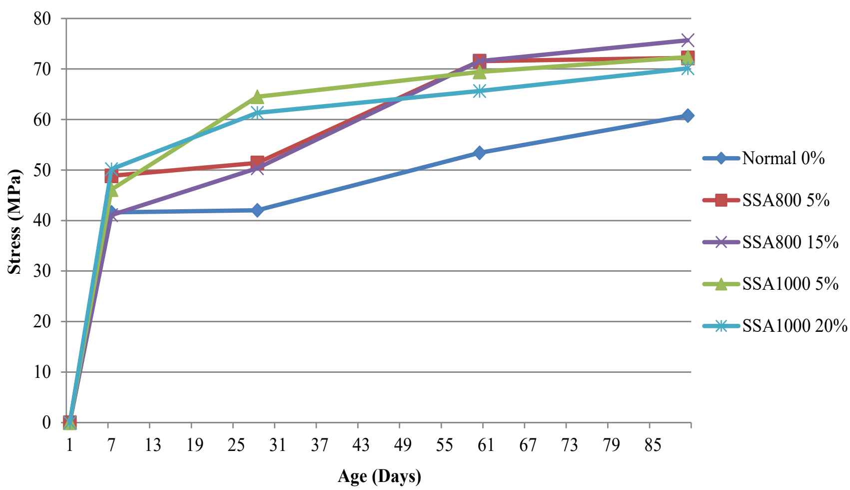

Figure 5: Compressive Strength of SSA Mortar Specimen with Respect to Two Different Incineration Temperatures

The compressive strength of SSA mortar with respect to incineration temperatures of 800°C and 1000ºC, which designated as SSA800 5%, SSA800 15%, SSA1000 5% and SSA1000 20% are demonstrated in Figure 5. It shows that all the SSA specimens developed its strength as the curing days prolonged. The higher strength development occurred in the earlier stage of curing, and it starts to slow down after 60 days of age, ascribed to the higher amount of SiO_2 and CaO content in SSA.

Interesting to note that all SSA mortar specimens (both incinerated at 800°C and 1000°C) exhibited higher compressive strength corresponding to the control mortar with respect to age of curing. These findings also claimed by Tay *et al.* [14], which had proved that SSA could enhance the mortar properties and belief that other than chemical composition content, the temperature and duration used during the incineration process, may influence in producing good quality of SSA. Therefore, this finding verified that SSA which incinerated at temperature of 800°C and 1000°C, have potential to be used as partial cement replacement material in making mortar.

CONCLUSION

From discussion of the present study, the findings are outlined as follows:

a. Utilisation of SSA (produced by incineration temperature of 800°C and 1000°C) as cement replacement material in mortar mix, enhanced the compressive strength of the resulted SSA mortar.
b. The optimum SSA as cement replacement material can be as high as 20% replacement by weight of cement in mortar making.
c. Mortar that made of SSA incinerated at 800°C and replaced for 15% of cement attained the highest compressive strength.

It is suggested that this local made SSA has potential to be used as partial cement replacement material in making concrete or any reinforced concrete structure, such as wall panel, beam, slab etc. Further researches on long-term behaviour of SSA concrete need to be conducted before it is being practically used.

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