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Effects of Sand Cement Ratio to the Performances of Strength in Waste Treatment Sludge Mortar

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ABSTRACT

The aim of the study is to investigate the potential use of dewatered sludge cakes in mortar properties as building material. The sludge was collected from water treatment plant and the percentages used in the mixes were 2%, 4%, 6%, 8% and 10% by weight of sand in mortar. The specimen without sludge was prepared for comparison. The testing involved chemical analysis of sludges as well as compressive strength for hardened state properties. The samples were cured at 7 and 28 days, and the average of three samples of 50 mm cube samples was measured. Two types of mixes with different ratio of sand were used and compared in terms of performance in strength. The results revealed that the waste sludges had higher components of Zn, Cu, Pb and As which was trace element concentrations in the dry sludge samples. Comparisons of strength were made from two different types of sand ratio used in the mixes. It was observed that sludge in mortar performed better when mixed with ratio of 1:3 compared to 1:6. The optimum results of waste sludge mortar were denoted from the replacement of 2% of sludge in the mortar. It can be concluded that waste sludge as a result from the process of water treatment can be utilized as partial replacement of sand in mortars.

Key Words: sludge, compressive strength, mortar, mix design, performances.

1. INTRODUCTION

The consumption demand of clean water for living life and industries increases with the rise of rapid development in Malaysia. The growing population in Malaysia was estimated about 32.6 million in 2019 (Mahidin, 2019), as well as industrial sector, which was accounted for more than 36.8% of the nation’s GDP in 2014, and the highest contributors were the sectors of electronic industry, construction industry, and automotive industry (Bada, 2018). Due to

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these developments, water supply management has become important to meet the demands of the population.

Among all the industries that contribute towards major economic growth of the country, the construction sector contributes the most. The highest value of construction was recorded in the state of Selangor with a contribution of 24.5% compared to Johor (16.5%), Kuala Lumpur (15.8%), Sarawak (8.6%), and Penang (6.4%) (Bada, 2018). These has made the state of Selangor to be the main national economic drivers towards GDP Malaysia. Therefore, the water treatment plant in Selangor is among the largest produced clean water which is estimated about 4476 million liters per day (Selangor Water Works, 2020). However, it is estimated that the quantity of over 2.0 million tons of water treatment sludge or residual (WTS) is produced annually by water operators across Malaysia. Due to the cost of finding new landfill (scarcity land) and the need for sustainable best practices, sludge disposal has become a global problem, and it is necessary to look for alternative reuse of sludge (Breesem, Faris, and Abdel-Magid, 2014). Therefore, final products of treatment water known as sludge has become a subject matter from the government to reduce waste generation. Most sludge is transported to designated landfill to damp the water residual waste (WSWM, 2015).

Water treatment plants produce a wide variety of waste products as well as safe drinking water. These residuals may be organic and inorganic in liquid, solid and gaseous forms depending on the source of raw water and the types of treatment processes including coagulation/filtration, precipitative softening plant, membrane separation, ion exchange and granular activated carbon (Robinson, and Witko, 1991). One of the most common methods employed to remove suspended particles and colloids from raw water is the addition of metal salts to initiate a coagulation–flocculation process. Alum sludge is a by- product of the treatment plants that use aluminum as coagulant. The treatment uses coagulant such as aluminium sulphate known as alum, the iron-based salts ferric chloride and ferric sulphate, which are the resultants of chemical reaction of Al and Fe salts in alkaline conditions to form hydroxide precipitates that remove impurities via co-precipitation, sorption, flocculation and settling (Dassanayake, Jayasinghe, Surapaneni, et al., 2015; Turner, Wheeler, Stone, et al., 2019).

In general, the construction industry in Malaysia plays a vital role towards the country's development (Shehu, Endut, Akintoye, et al., 2014). The increasing demand in rapid development has attributed to the global consumption of usage of resource materials, for instance the utilization of natural aggregates and sand which are the main components in concrete and mortar production. However, the environmental concern is one of the main challenging issues affecting the natural concrete aggregate production (Ismail, Hoe, and Ramli, 2013). The exhausts of these materials have become pertinent if necessary, however, action taken to save the natural resources is prohibited. Therefore, it has become important to find alternative practices to decrease the requirement needed to produce innovative building materials due to the increase of waste generation of these materials. Waste treatment sludge is a hazardous waste produced from purifying water, which has been identified as a potential alternative ingredient in making concrete. Water treatment sludge has the potential to be used as building material in many aspects of studies in terms of strength and durability including replacement of mixing water (Roccaro, Franco, Contrafatto, et al., 2015), partial replacement of cement (Owaida, Hamid, Abdullah, et al., 2013), partial replacement of fine aggregates (Andrade, Wenzel, Da, et al., 2018), and application in civil engineering (Da Silva, Morita, Lima, et al., 2015). Among those researches, there is less information regarding the utilization of sludge in mortar properties focusing on comparison between two mixes of sand cement ratio, respectively. This study aims to investigate the possible use of sludge as partial replacement of sand in mortar properties and tested for compressive strength. Finally, the addition of sludge would improve the properties of mortar as well as to reduce environmental impacts associating

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from its waste generation and landfill disposals.

2. EXPERIMENTAL PROGRAM

2.1 Cement

Ordinary Portland Cement (OPC) complying with BS EN 197-1: 2011 was used in all mortar mixes. The chemical composition of the cement is as shown in Table 1. The determination of major and trace element present in cement based composites followed the validation of EDXRF procedure by Mijatović et al. (2019). It was observed that high percentages of Ca in cement samples were due to the presence of limestone ($CaCO_3$) used as raw material in cement production.

Table 1 Concentration of Elements with EDXRF Analysis

Major Element	Portland Cement (%)
Si	2.1
Al	0.497
Fe	2.476
Ca	49.01
Mg	0.201
S	0.496
K	0.384
Ti	0.123
P	-
Mn	973.2 (ppm)
Sr	-
Trace element	
Cr	12.1 (ppm)
Zn	447.5 (ppm)
Cu	-
As	-
Ni	-
Pb	-

2.2 Fine Aggregate

Natural river-washed quartz sand complying with BS 882: 1992 was used as fine aggregate respectively. The sand grading is shown in Table 2, and the fine modulus of sand is 2.10.

Table 2 Grading of Fine Aggregate

Sieve Size (mm)	Mass of each Sieve (g)	weight Retained (g)	Net Weight (g)	Retained weight (g)	Passing weight (g)	Cumulative percentage passing (%)
2.36	488	513	25	25	475	95
1.18	353	520	167	192	308	62
0.6	304	398	94	286	214	43
0.3	275	442	167	453	47	9
0.15	258	298	40	493	7	1
Pan	354	363	7	500	0	0

2.3 Waste Sludge

Waste sludge in dry condition as shown in Figure 1 was collected from water purification plant at Bukit Badong, Selangor. Dewatered sludge cakes are the by-products from processing of water treatment plant to provide clean water supply around the state of Selangor. The raw water is mainly sourced from surface water collected by several dams,

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lakes and rivers, and treated at a nearby water treatment plant. In this study, the raw water is collected from Sungai Selangor Dam and Sungai Tinggi Dam, with a capacity of 950 million liters per day (MLD) (Selangor Water Works, 2020). Sludge produced during the coagulation and flocculation process is passed through the dewatering facility, and the dehydrated sludge is subject to land filling. The representative samples of dehydrated sludge were tested for chemical analysis using energy dispersive X-ray fluorescence (ED-XRF) technique.

Figure 1: Sludge Resulting from Water Treatment Process

2.4 Mix Proportion

In order to investigate the strength properties of waste sludge mortar, 7 mixes were employed. Two types of mix ratio used were 1:3 and 1:6, respectively. The free water to cementitious ratio was maintained constant at 0.5 for all mortar mixes. The compositions of sludge used as substitute for fine aggregate were 0%, 2%, 6%, 8% and 10% in cement mortar as shown in Table 3 and Table 4.

Table 3 Mix Proportion with 1:3 Ratio

	S0%	**S2%**	**S4%**	**S6%**	**S8%**	**S10%**
Cement (g)	625	625	625	625	625	625
Sand (g)	1875	1837	1800	1762	1725	1687
Water (g)	313	313	313	313	313	313
Sludge (g)	0	38	75	113	150	188

Table 4 Mix Proportion with 1:6 Ratio

	S0%	**S2%**	**S4%**	**S6%**	**S8%**	**S10%**
Cement (g)	357	357	357	357	357	357
Sand (g)	2143	2100	2057	2014	1972	1929
Water (g)	180	180	180	180	180	180
Sludge (g)	0	43	86	129	171	214

2.5 Compressive Strength

The trial mix used mortar cubes sized 50 mm x 50 mm x 50 mm for compressive strength testing. The test was carried out according to ASTM C109 for each mix design, and the cubic mortars were tested at 7 and 28 days. The average of three values was taken as the strength value for all batches.

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3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

The grading curves of fine aggregates are shown in Figure 2. The sand used in this study satisfied the grading requirements of fine aggregate according to BS 882:1992 which was suitable for mortar mixtures.

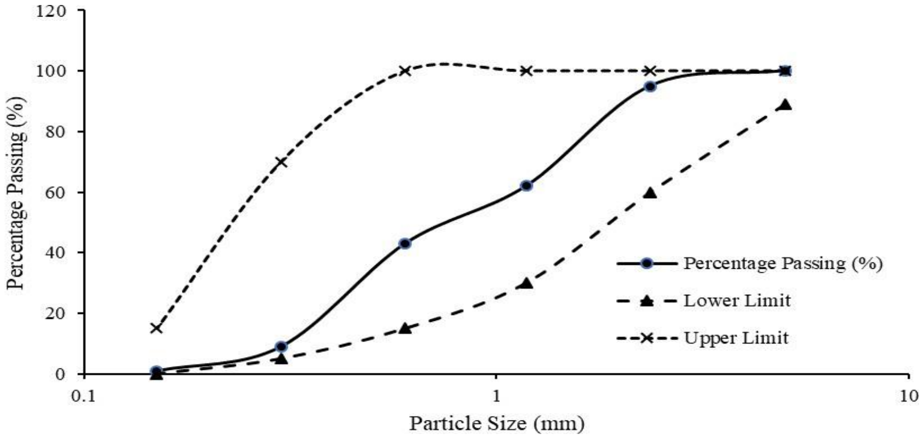

Figure 2: Grading Curves of Sand

3.2 Characteristics of water treatment sludge

The chemical characteristics of water treatment sludge are shown in Table 5. The sludge was collected from water treatment plant (WTP) in Bukit Badong, Selangor, and the water was treated by using aluminum salt in the process of coagulation and flocculation. Major chemical compositions such as Si, Al, Fe, and Ca were found in the sludge, and these parameters were the main components of the sludge. Other trace metals were also found in the dried sludge. The higher elemental concentrations such as Zn, Cu, Pb, and As are thetypes of heavy metals which are harmful to the environment and population. Most of the chemical compositions and trace elements have similar characteristics with other studies (Ahmad, Ahmad, and Alam, 2016).