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Water Treatment Sludge Stabilizer Binder by Waste Paper Sludge Ash for Solidification/Stabilisation Technique

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Abstract: Waste Paper Sludge Ash (WPSA) was used as stabilizer binder to treat water treatment sludge (WTS). This study was conducted to treat WTS by using WPSA in Solidification/Stabilisation (S/S) technique. WPSA was utilized at 10%, 20%, 30%, 40% and 50% to treat 200g WTS at binder-to-sludge (B/S_d) ratio 1:1. The control sample was 100% Ordinary Portland Cement (OPC). The compressive strength and leaching test on WTS treated with WPSA at specified percentage were performed. The compressive strength was conducted on sample cured at age 1, 3, 7 and 28 days. The leaching test was conducted only on sample cured at age 28 days. The minimum target compressive strength was 0.34 MPa as accordance to USEPA. The maximum metals acceptance criteria as stipulated by Kualiti Alam were 1.0, 5.0, 100.0, 100.0 and 5.0 mg/L for cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu) and chromium (Cr) respectively. Results showed that the compressive strength decreases with increasing WPSA content but exceeded the minimum target strength. The compressive strength increases with respect to curing days. The optimum content of WPSA to treat WTS was 50% (W5). The compressive strength of W5 with high WPSA content was the first exceeded the minimum compressive strength. The concentration of metals decreases with respect to percentage of WPSA added.

Keywords: Metals leaching, Stabilizer binder, Strength, Solidification/Stabilization technique, WPSA, WTS

1. Introduction

Water treatment sludge (WTS) has been a major global problem and dealing with it remains a challenge for scientists and engineers. WTS is expected to increase annually parallel to the continuous increase in population [1]. Every year, 2 million tons of WTS is produced by water operators in Malaysia to cope with the increase population number of 16, 800/year [2], [3]. WTS can be highly toxic for environment and human health. WTS has a tendency to cause soil pollution when it disposed on the land or even from acidic rain. The exposure tends to cause the breaking down soils and releasing heavy metals into streams, lakes, rivers and groundwater [4]. Metals in untreated WTS tends to accumulate although the metals are usually found at low level of concentration. Due to the hazardous effects that can cause to environmental and human health problems prior to land disposal, issues of WTS needs to be treated before dump should be considered.

One of sludge treatment technique is Solidification/Stabilisation (S/S) technique. The application of S/S technique to treat WTS is somehow limited as WTS is always considered to be non-toxic. Thus, incineration and landfilling are alternative sludge treatment practiced till today [5]. S/S technique is simple in operation and should be implemented

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prior the disposal of sludge [1], [6]. S/S technique works by converting the contaminants in less soluble forms, mobiles and toxics [7]. The effectiveness of S/S technique depends on type of binder used. The main principle behind S/S technique is the hydration of a binder by the liquid fraction in the waste to obtain a new solid impermeable product [8].

Ordinary Portland Cement (OPC) is a binder usually used in S/S technique [9, 10]. During the implementation of S/S technique using OPC, water in the sludge reacts chemically with it to form hydrated silicates and aluminates (C-S-H) gel resulting in a solid monolithic mass. The development of C-S-H gel assists in reducing the amount of $Ca(OH)_2$ that tends to lower down the strength of end products [11]. Indeed, a binder from industrial waste materials also offers effective performance in treating the sludge.

Waste Paper Sludge Ash (WPSA) is an industrial waste material which produced in the form of ash. WPSA is produced by incinerating the waste paper sludge to reduce the volume of waste sludge to be handled in paper manufacturing and recycling industries. WPSA contains organic and inorganic fillers such as kaolin clay, calcium carbonate, talc and titanium dioxide [12]. WPSA reported potentially used as glass ceramic product [13], soil improvement [12], as supplementary cementitious materials [14] and as activator in geopolymer materials [15], [16].

Although WPSA was well-utilized in many applications, limited study was found to utilize WPSA for sludge treatment. From this point of view, WPSA is believed can poses the function as sludge stabilizer binder which would not only treat the sludge but would also reduce the amount of waste from paper industry to be landfilled. The present study aims to utilize WPSA in blends with OPC as a stabilizer binder for S/S technique to treat WTS.

2. Materials

Fresh WTS from a sedimentation tank was collected from a water treatment plant managed by Aliran Utara Sdn. Bhd., Perak Darul Ridzuan, Malaysia. The water treatment plant produces 126 million liters of treated water daily. The characteristics of WTS are shown in Table 1.

Table 1 - Characteristics of WTS

Metals	WTS	Waste Acceptance Criteria
Cd (mg/L)	0.003	1.0[a]
Pb (mg/L)	0.004	5.0[a]
Ni (mg/L)	0.004	100.0[a]
Cu (mg/L)	0.01	100.0[a]
Cr(mg/L)	0.02	5.0[a]
Compressive strength (MPa)	-	0.34[b]

[a] Waste Evaluation Guidelines, Kualiti Alam Sdn. Bhd., Malaysia (Yin et al., 2008)
[b] USEPA minimum compressive strength of contaminants for toxicity characteristics (USEPA, 1998)

WPSA was collected from Malaysian Newsprint Industries (MNI). The industry is located in Mentakab, Pahang Darul Makmur, Malaysia. It is about 100 tonnes/day WPSA is produced by the industry.

OPC was obtained from Tasek Cement Berhad and placed in Concrete Laboratory, Faculty of Civil Engineering, UiTM Shah Alam, Selangor Darul Ehsan, Malaysia. OPC used was confirming to MS 522: Part 1: 1989. The XRF result of WPSA and OPC are given in Table 2.

Table 2 - XRF results of WPSA and OPC

Compounds	Compositions	
	WPSA	OPC
CaO	63.0	50.67
SiO_2	20.0	13.96
Al_2O_3	5.70	9.36
MgO	0.99	4.23
Fe_2O_3	2.90	-
SO_3	3.50	-
Na_2O	0.08	-
K_2O	1.20	0.22
LOI	2.63	-
Others	-	21.56

3. Methods

Five different mix ratios of WPSA in the cement matrix were studied. The mix ratio of WPSA and OPC to treat WTS are given in Table 3 and prepared in triplicate [6]. WPSA and OPC were mixed for a minute in dry condition to prepare a stabilizer binder for WTS. The mix of WPSA and OPC was then added with 200g WTS at binder-to-sludge (B/S_d) ratio 1. The mixture was mixed at high speed for 3 minutes to attain its homogeneity [17]. A cube mould size of 5 cm^3 was used to prepare the cube samples [18]. The samples were de-moulded after 24 hours. Curing times of 1, 3, 7 and 28 days were then taken into place to allow the hydration process.

Table 3 - Mix ratio of WPSA and OPC to treat WTS

Mix ratio	WPSA		OPC		WTS
	(%)	(g)	(%)	(g)	(g)
W0	0	0	100	100	200
W1	10	10	90	90	200
W2	20	20	80	80	200
W3	30	30	70	70	200
W4	40	40	60	60	200
W5	50	50	50	50	200

The solidification and stabilization of treated WTS were evaluated by compressive strength and metals leachability respectively.

Compressive strength was conducted on samples at specified curing days using Universal Testing Machine (UTM) accordance to BS 1881-116: 1983. A load applied was begin from 0 kN till the failure occurred. The rate of compression was 1.52 mm/min [19] The density of the sample was also determined. The resulting strength was average value of three samples. The minimum compressive strength of 0.34 MPa was targeted.

Samples tested for compressive strength were arranged for metals leaching analysis using Toxicity Characteristics Leaching Procedure (TCLP), USEPA Method 1311 to identify whether or not a waste is hazardous. In the testing stage, the tested samples (<9.5 mm) was mixed with the extraction liquid at a liquid-to-solid ratio (L/S) of 20:1 [20]. Each extraction process was operated by agitating the mixture at 30 rpm for 18 h. Cd, Pb, Ni, Cu, and Cr concentrations in the extraction leachate were analyzed by DR 2010 spectrophotometer in accordance with standard Hatch Method [21].

4. Results and Discussion

The compressive strength was performed on the solid treated WTS at 1, 3, 7 and 28 curing days. The results for compressive strength of solid treated WTS is shown in Fig. 1. In general, compressive strength of solid treated WTS was within the allowable limit (0.34 MPa). The highest compressive strength was obtained by control specimen (W0) of 1.43 MPa at 28 days. The lowest compressive strength was occurred at 50%WPSA (W5) taken at 28 days. It can be visualized from Fig. 1 that the compressive strength continuously increases along with curing days. The calcium oxide (CaO) in WPSA affected the strength development of solid treated WTS. The CaO contains in WPSA is 63.0%, higher than that contain in OPC. CaO is an essential compound in calcium silicate hydrate (C-S-H), required for hardening of cementitious mixtures [22], [23].

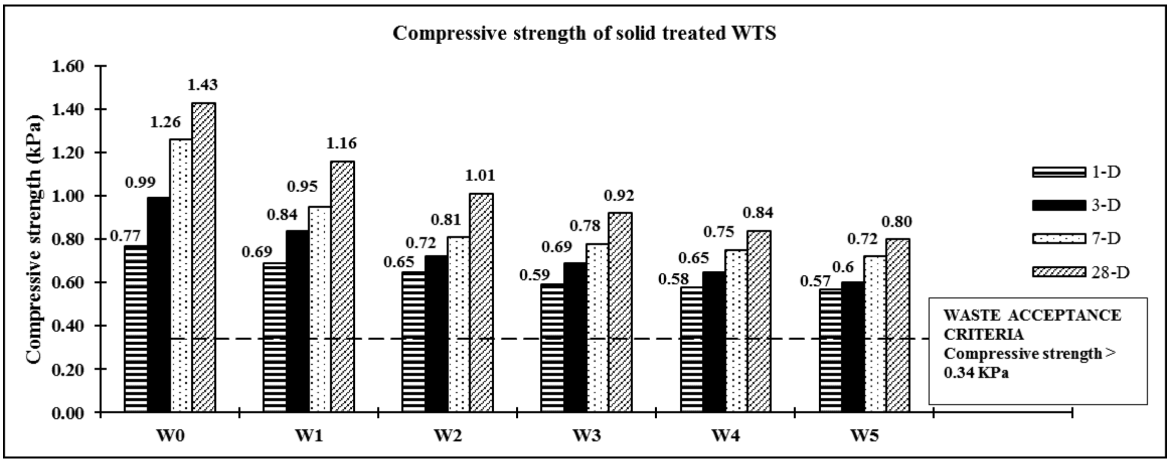

Fig. 1 - The compressive strength of solid treated WTS

The compressive strength however, was decreasing with respect to WPSA percentage replacement. The compressive strength was reduced from 1.16 to 0.80 MPa when more than 10%WPSA was used to treat WTS. This had been revealed by Nurliyana et al., [1]. The utilization of more than 10% WPSA limits the strength development of the S/S end-product. However, the optimum mix proportion of WPSA was determined based on the compressive strength whichever firstly exceeded the minimum strength of 0.34 MPa with high cement replacement percentage at age 28 days. W5 (50%WPSA) with high WPSA replacement percentage was the optimum WPSA content with 0.80 MPa strength at age 28 days. The correlation between the compressive strength of solid treated WTS and W5 until age 28 days is shown in Fig. 2. The correlation was R-squared (R^2) of 96%. The compressive strength was seen developed higher than the minimum strength from the first day.

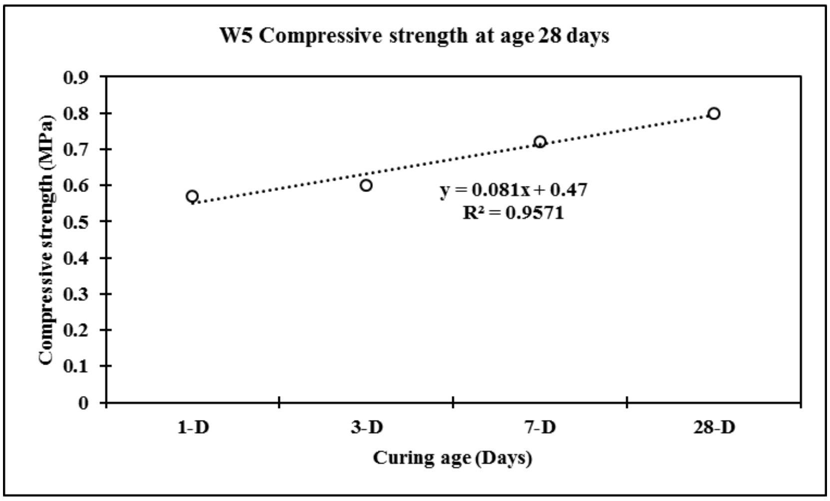

Fig. 2 - Compressive strength of solid treated WTS at age 28 days

The sample was also tested for density. Results of density of solid treated WTS is shown in Table 4. The density of solid treated WTS were increased as the percentage of WPSA increase. The density of solid treated WTS varied between 1095.27 to 1273.83 kg/m^3 at age 28 days. The density of control sample and W3 were nearly the same which was 1191.5 kg/m^3 and 1195.55 kg/m^3 respectively. The W5 sample with 50%WPSA attained the highest density of 1258.74 kg/m^3. This indicates that the density of solid treated WTS was affected by the content of WPSA once it was hardened properly.

Table 4 - The results for density of solid treated WTS

Sample	Density at age 28 days (kg/m^3)
W0	1191.15
W1	1095.27
W2	1146.82
W3	1195.55
W4	1273.83
W5	1258.74

The leaching test was carried out on sample cured at age 28 days. Cd, Pb, Ni, Cr^{6+} and Cu were the metals examined during the leaching test. The concentrations of metals varying with WPSA percentages are shown in Fig. 3 to Fig. 7. It was observed that metals concentration from solid treated WTS were higher than those in the original WTS. The concentrations of metals were also lower than metals concentration extracted from W0 which contains OPC only. The Ni concentration was observed totally removed. The Pb, Cr^{6+} and Cu concentration were all below W0 once WPSA was added. Results also showed that Cd concentration was reduced with the increment of WPSA percentage although at 10% (W1) and 20% (W2) showed little increment in Cd concentration. This clearly indicates that WPSA was effective in stabilizing the metals. On the other hand, it can be hypothesized that solid treated WTS contained some metals that may originated from OPC. OPC contained Pb, Zn, and Cr that may derive from the natural ores or alternative materials and fuels that are used in its manufacturing process [20]. Furthermore, the alkalinity of solid treated WTS affects the metals leaching capability, as well. The alkalinity of solid treated WTS depends on the content of CaO and calcium hydroxide ($Ca(OH)_2$) derived from OPC and WPSA. OPC and WPSA have 50.67% and 63.0% of CaO respectively. A larger amount of Ca in the form of CaO and $Ca(OH)_2$ in the solid treated WTS resulted in a reduction of heavy metals leaching [11]. From all the metals concentration obtained, it can be stated that WPSA was successfully stabilized the WTS. All the metals concentrations were detected lower than the allowable limit as stipulated by Kualiti Alam.

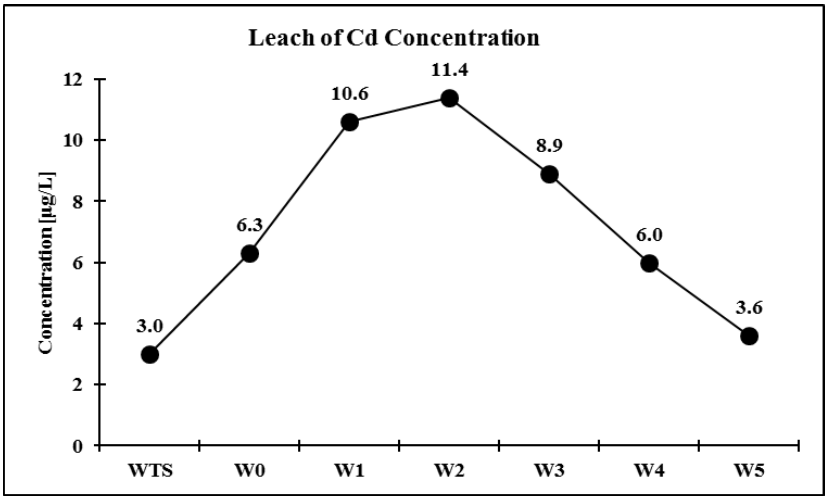

Fig. 3 - Cd concentration of solid treated WTS

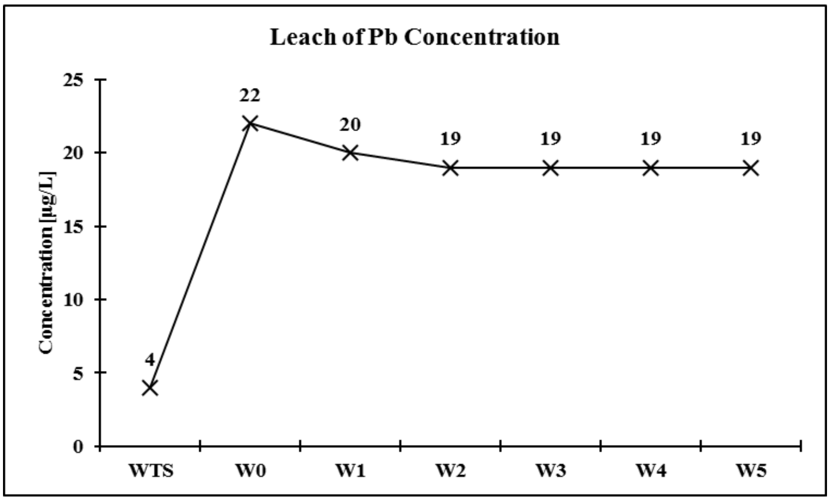

Fig. 4 - Pb concentration of solid treated WTS

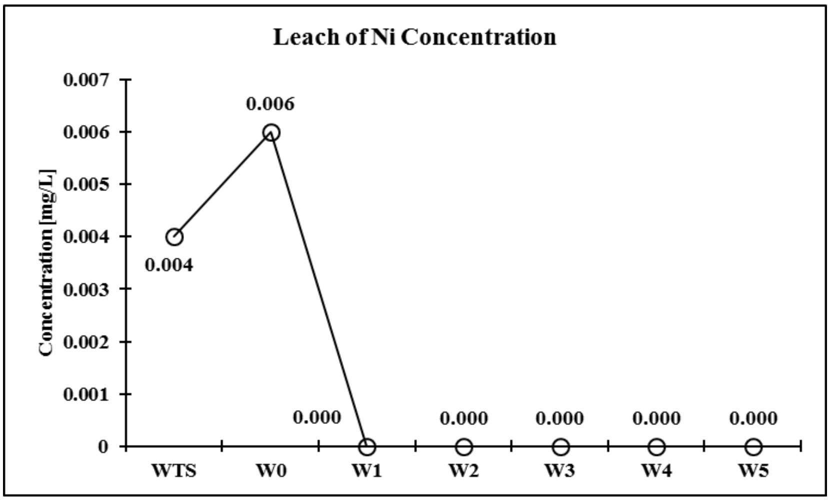

Fig. 5 - Ni concentration of solid treated WTS

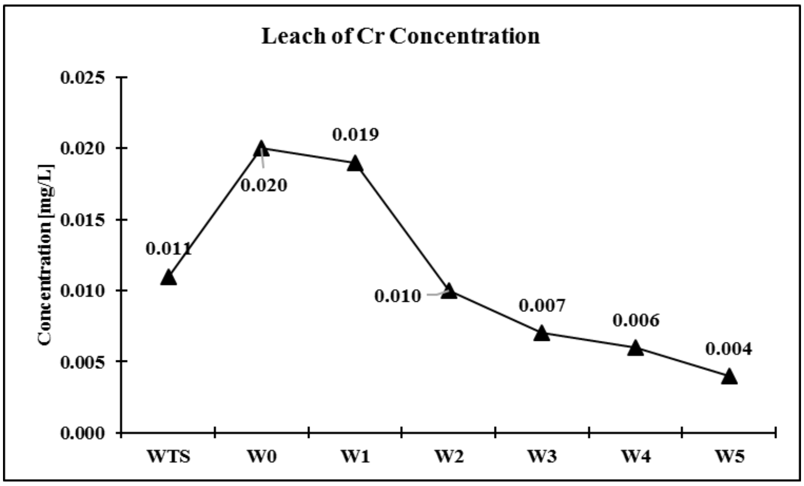

Fig. 6 - Cr concentration of solid treated WTS

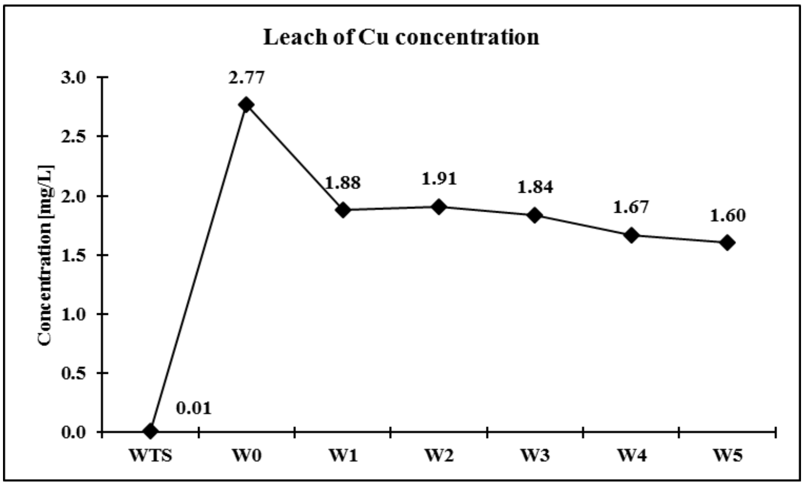

Fig. 7 - Cu concentration of solid treated WTS

Summary

The toxicity of WTS differs with it source and becomes difficult to be handled. An appropriate technique must be carefully choosing to ensure the solidity and the stability of WTS. The WTS treatment by S/S technique using WPSA seems effective. The following conclusions were drawn:

- The optimum mix design for S/S of 200g WTS using WPSA and OPC at $B/S_d = 1$ was 50% WPSA and 50% OPC.
- The compressive strength of solid treated WTS were found inclining with curing days.
- The compressive strength of solid treated WTS were found declining with WPSA percentage.
- The CaO content in the OPC and WPSA affected the compressive strength of solid treated WTS.
- The density of solid treated WTS was affected by the percentage of WPSA once hardened properly.
- Metals concentration extracted from the solid treated WTS was decreased. This might be due to the metals originated from OPC manufacturing process and the alkalinity phase.

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