Determination of optimum ordinary Portland cement content in solidifying/stabilizing mineral sludge

I Nurliyana
Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
Email: nurliyana_ismail@ymail.com

Abstract. Binder plays important role in Solidification/Stabilisation (S/S) technique for sludge treatment. However, mineral sludge namely water treatment sludge (WTS) and ceramic sludge (CS) are rarely treated using S/S technique. Therefore, this study was conducted to obtain optimum percentage of Ordinary Portland Cement (OPC) content as a binder in S/S technique to treat the mineral sludge. Twenty (20) OPC mix proportions at 10% to 100% OPC with 10% increment were prepared to treat both 200 g WTS and 200 g CS. Binder-to-sludge (B/Sd) ratio of one (1) was used. Air curing was applied for all mixes. Compressive strength was conducted at 28 curing days. The compressive strength of treated mineral sludge was then compared to the requirement stipulated in Waste Acceptance Criteria in Landfill at 0.34 MPa. It was found that the optimum percentage of OPC to treat 200g WTS and 200g CS were 50% and 60% respectively.

1. Introduction

Treatment plant produces a sludge residue as the final product of the process of water and wastewater treatment. The sludge residue is generated by discharging the clear water from sedimentation tanks into the waterline before the sludge is de-watered and ready for disposal. Although current technologies such as ultrafiltration, crystallization, electrolysisa, evaporation, ion exchange and adsorption have been proposed as sludge treatment, these technologies are not encouraged for wide application in small factories due to its high cost required although for small quantity of sludge production [1]. Thus, landfilling is always being a chosen sludge treatment for small factories. Due to this, a good practice of sludge treatment especially for small industries in minimizing the sludge impact on the environment is required. In this study, the mineral sludge used are water treatment sludge (WTS) and ceramic sludge (CS). The sludge used contains minerals which are organic/inorganic compounds and metals. The mineral sludge used are generated by a physic-chemical process of water and wastewater treatment from water supply industry and tile manufacturer industry respectively. Both WTS and CS are also believed contain suspended solids and metals in high quantity.

Solidification/Stabilisation (S/S) technique is a sludge treatment method which could reduce sludge toxicity and improve sludge handling prior to its disposal. With suitable type of binder used in this technique, better characteristics of mineral sludge prior to landfill disposal can be achieved. The original form of sludge could be converted into solid form and the toxic level of the sludge could also be reduced [2-3]. Typical binders used in S/S technique are including cement, organic polymers and lime [4]. The choice of the right type of binder will affect the effectiveness of the S/S technique.
Ordinary Portland Cement (OPC) is a main binder in S/S technique used to treat the sludge. It is due to the characteristics of OPC itself which could produce high strength, low permeability and high durability of end products depending on the temperature, the particle shape/size and the presence of accelerators/retarding agents at medium and later ages [5-6]. The pH of OPC is between 12.5 and 13.5, would also help in limiting the mobility of minerals and metals in the sludge through precipitation and sorption reaction [2, 7]. Besides, OPC is widely available and it is a versatile material [8-9].

The literature concerning on the application of OPC in S/S technique for sludge treatment can be listed as follows: microscopic and macroscopic of stabilized/solidified synthetic zinc hydroxide sludge using OPC [10], effects of setting and hardening process of various percentages of OPC for stabilization and solidification of sewage sludge [11], affectivity identification of OPC in immobilizing heavy metals and in achieving a minimum unconfined compressive strength of 50 psi (0.34MPa) from an electroplating industry sludge [7], hydro-carbons from stabilized/solidified refinery oily sludge using OPC [12], the effectiveness of OPC on mechanical strength and metal leaching of sludge containing Pb [13], and observation on use of OPC as a solidifying agent for solidification of tank bottom sludge[14].

Limited study has been conducted on the use of OPC to treat WTS and CS. Therefore, the optimum OPC to treat WTS and CS in S/S technique is determined to fulfill the Waste Acceptance Requirement at Landfill [15]. The optimum OPC for WTS and CS is based on the compressive strength obtained and should be more than 0.34MPa. The efficiency of OPC in S/S technique to treat WTS and CS is also evaluated.

2. Materials and Methods

2.1. Sludge sampling

WTS was collected from sedimentation tank in Perak, Malaysia. It is a fresh sludge which no further treatment implemented onto it. The water resource of the treatment plant is dam. The colour of WTS is dark brown to show that it is high in degradable matter.

CS was collected from a sludge tank at ceramic glazed wall and tile manufacturing industry in Negeri Sembilan, Malaysia. It is a fresh sludge categorized under Schedule Waste in accordance with Environmental Quality Act 1974 [16]. It might contain metals and it is light brown in colour with high suspended matter. The characteristics of WTS and CS are presented in Table 1.

| Metals   | WTS       | CS        | Waste Acceptance Criteria |
|----------|-----------|-----------|---------------------------|
| Cd (mg/L)| 0.003     | -         | 1.0\(^{a}\)               |
| Pb (mg/L)| 0.004     | 0.1857    | 5.0\(^{a}\)               |
| Ni (mg/L)| 0.004     | 0.037     | 100.0\(^{a}\)             |
| Cu (mg/L)| 0.01      | -         | 100.0\(^{a}\)             |
| Cr (mg/L)| 0.02      | 0.02      | 5.0\(^{a}\)               |
| **Compressive strength (MPa)**| **-** | **-** | **0.34\(^{b}\)** |

\(^{a}\) Waste Evaluation Guidelines, Kualiti Alam, Sdn. Bhd. Malaysia [17]

\(^{b}\) Waste Acceptance Requirements at Landfill [15]

2.2. OPC collection

OPC was obtained from Tasek Cement Berhad and placed in Concrete Laboratory, Faculty of Civil Engineering, UiTM Selangor, Malaysia. OPC used was confirming to MS 522: Part 1:1989. The chemical composition of OPC from X-Ray fluorescence (XRF) analysis are shown in Table 2.
Table 2. The chemical compositions of OPC.

| Compounds | Compositions (%) |
|-----------|------------------|
| CaO       | 50.67            |
| SiO₂      | 13.96            |
| Al₂O₃     | 9.36             |
| MgO       | 4.23             |
| Fe₂O₃     | -                |
| SO₃       | -                |
| Na₂O      | -                |
| K₂O       | 0.22             |
| LOI       | -                |
| Others    | 21.56            |

2.3. Binder preparation

The binder was prepared at binder-to-sludge (B/S) ratio of 1. OPC and sludge were blended at high speed for three (3) minutes using a rotary mixer. Ten (10) mix ratios of OPC to treat WTS and CS are given in Table 3. Each mix was prepared in triplicate. A cube mould size of 50mm x 50mm x 50mm was used to cast mixes and cubes were de-moulded after 24 hours of casting. Cubes were cured for 28 days at air condition to allow hydration process.

Table 3. Mix ratios of OPC to treat mineral sludge.

| Mix ratio sludge-OPC | OPC (%) | OPC (g) | WTS (g) | CS (g) |
|----------------------|---------|---------|---------|--------|
| P1                   | 10      | 20      | 200     | 200    |
| P2                   | 20      | 40      | 200     | 200    |
| P3                   | 30      | 60      | 200     | 200    |
| P4                   | 40      | 80      | 200     | 200    |
| P5                   | 50      | 100     | 200     | 200    |
| P6                   | 60      | 120     | 200     | 200    |
| P7                   | 70      | 140     | 200     | 200    |
| P8                   | 80      | 160     | 200     | 200    |
| P9                   | 90      | 180     | 200     | 200    |
| P10                  | 100     | 200     | 200     | 200    |

2.4. Analytical methods

Compressive strength was conducted on cubes at 28 curing days. The test was conducted using Universal Testing Machine (UTM) in accordance with BS 1881-116: 1983. A load applied started from 0kN till the failure occurred. The results were taken in average value of three (3) cubes.

3. Results and Discussions

The solidification of sludge-OPC were measured for 28 days of curing periods. Control specimens were raw sludge and 100% OPC (P10). The evaluation on solidification of the sludge-OPC was assessed based on the compressive strength at 28 days. Total of twenty (20) mixes OPC to treat WTS and CS were studied. The compressive strength value must exceed the allowable limit stipulated in Waste Acceptance Requirement at Landfill [15] in order to determine the optimum percentage of OPC required for WTS and CS treatment.

In general, the strength development is dominated by calcium-silicate-hydrate (C-S-H) and calcium hydroxide (Ca(OH)₂) which are the hydration products generated through cement hydration process [18]. When OPC reacts with water, C-S-H comprises 70% to 80% of the hydration products contributes to the strength development [17]. The increase in compressive strength of treated WTS and
CS by OPC therefore, could be attributed to the increase of hydration products in the mix. It is therefore, the higher substitution of OPC has resulted in increase of compressive strength of treated WTS and CS.

3.1. Optimizing OPC in solidifying WTS
The optimum OPC in S/S technique used to treat WTS was determined. The optimum OPC for WTS treatment was based on the comparison of strength of treated WTS to the Waste Acceptance Requirement at Landfill at 0.34 MPa.

Figure 1 shows that the higher the OPC percentage, the higher the compressive strength of treated WTS. Minimum and maximum compressive strength of 0.25MPa and 7.47MPa were obtained respectively at 28 age of days. The optimum percentage of OPC for WTS treatment was found to be at 50% OPC labelled as P5. The compressive strength of treated WTS by P5 was obtained higher than 0.34MPa.

3.2. Effects of OPC in WTS treatment
Compressive strength of treated WTS by P5 with 50% OPC was compared to compressive strength of raw WTS and to the criteria required for sludge disposal in landfill. Figure 2 shows the compressive strength of treated WTS as a function to reduce the OPC content in S/S technique to treat WTS prior its disposal. It is shown that the strength of treated WTS by P5 has exceeded the strength of raw WTS as well as the minimum strength of 0.34MPa. The compressive strength of 1.43MPa was obtained for P5 at 28 age of days. Although higher compressive strength of the treated WTS would be preferable to ensure the durability of the treated WTS to well protect the landfill area [19], it would be not worth if more than 50% OPC was used for WTS treatment. It could be said that the treated WTS by using 50% OPC has met the strength requirement and it could be safely disposed in a landfill area. The high consumption of OPC in P10 with 100% OPC to treat WTS could be recommended to be used as lightweight construction materials.

The compressive strength of treated WTS is highly depending on the water content contains in WTS and on the degree of hydration of OPC [5]. Due to that, the P5 with 50%OPC might sufficiently hydrate at water content contains in WTS. Since the water source of the treatment plant is a dam, slight amount of metals can also be said be in WTS and believed were not given any effect to the strength of the treated WTS.
The compressive strength of treated WTS in comparison to raw WTS and Waste Acceptance Criteria in Landfill

3.3. Optimizing OPC in solidifying CS

The recommended strength of sludge to be disposed in landfill is 0.34MPa as outlined in Waste Acceptance Criteria in Landfill [15]. The optimum percentage of OPC in S/S technique to treat CS was attained by P6 at 60% OPC. The compressive strength of treated CS by P6 was the nearest strength achieved to the 0.34MPa. The compressive strength achieved was 0.91MPa at 28 age of days. The compressive strength of treated CS by various OPC mix proportions is presented in Figure 3.

![Figure 2. The compressive strength of treated WTS in comparison to raw WTS and Waste Acceptance Criteria in Landfill](image)

3.4. Effects of OPC in CS treatment

From Figure 4, it shows that highest compressive strength was obtained when 100% OPC labelled as P10 was used to treat CS. The compressive strength of P10 is clearly higher than the compressive strength of raw CS and P6 (60% OPC). Similar to those of WTS, higher compressive strength is preferable to produce more durable treated CS that could prevent metals leaching. However, an optimum 60% OPC to treat CS could be considered enough to be used to treat CS which has exceeded the minimum landfill requirement of 0.34MPa.

The presence of heavy metals in raw CS may affect the strength development and the hydration degree of OPC. The increment of strength of treated CS could be attributed by the metals content in the raw CS. The raw CS might contain metals that could assisting in the strength development. Otherwise, the presence of Pb and Ni in raw CS would inhibit the cementation process hence limiting the strength development of the treated CS [16]. The metals in CS could react with Ca(OH)$_2$ resulted in insoluble compounds in the form of metal hydroxide [20, 21] thus reducing the strength.
4. Conclusion

WTS and CS were treated using OPC as solidifying binder in S/S technique. The conclusions of the present study can be drawn as follow:

1. The use of 100% OPC to treat WTS and CS yielded the highest compressive strength.
2. The optimum OPC content to treat WTS is 50% at 1.43MPa compressive strength exceeded the minimum landfill disposal limit (>0.34MPa).
3. The optimum OPC content to treat CS is 60% at 0.91MPa compressive strength exceeded the minimum landfill disposal limit (>0.34MPa).

Acknowledgements

The authors would like to express greatest appreciation and gratitude to Universiti Teknologi MARA of Malaysia for giving an opportunity to conduct this study. Thanks are also express to Ministry of Education for the financial support (Fundamental Research Grant Scheme) as well as to Lembaga Air Perak (LAP) and Johan Ceramic Berhad for providing WTS and CS respectively.

References

[1] Silva M A R Mater L Souza-Sierra M M Corrêa R S and Radetski C M 2007 Journal of Hazardous Materials 147 986 – 990
[2] Wang F Wang H Jin F and Al-Tabbaa A 2015 Journal of Hazardous Materials 285 46 – 52
[3] Vinter S Montanes M T Bednarik V and Hrivnova P 2016 Journal of Hazardous Materials 320 105 – 113
[4] Sobiecka E Obreniak A and Antizar-Ladislo B 2014 Journal of Chemosphere. 111 18 – 23
[5] Bayar S and Talinli I 2013 Journal of Clean Technology Environmental Policy 15 157 – 165
[6] Chen Q Y, Tyrer M, Hills C D, Yang X M and Carey P 2009 Journal of Waste Management 29 390 – 403
[7] Malviya R and Chaudhary R 2006 Journal of Hazardous Materials. 137 207 – 217
[8] Alqam M Jamrah A and Daghlas H 2011 Jordan Journal of Civil Engineering 5(2) 268 – 277
[9] Cipurkovic A Trunic I Hodžić Z Selimbašić V and Djozic A 2014 Journal of Advances in Applied Science Research 5(6) 252 – 259
[10] Diet J N Moszkowicz P and Sorrentino D 1998 Journal of Waste Management 18 17 – 24
[11] Valls S and Vázquez E 2000 Journal of Cement and Concrete Research 30 1671 – 1678
[12] Karamalidis A K and Voudrias E A 2007 Journal of Hazardous Materials 148 122 – 135
[13] Gollmann M A C da Silva M M Masuero A B and dos Santos J H Z 2010 Journal of Hazardous Materials 179 507 – 514
[14] Taha R AMohamedzein Y E-A Al-Rawas A A and Al-Suleimani Y 2010 Journal of Geotechnology & Geology Engineering 28 15 – 25
[15] Environment Agency 2010 Waste Acceptance at Landfill (UK: Environment Agency)
[16] Environment Quality Act (EQA) 1974 Environmental Quality (Scheduled Waste) Regulations 1989 (Kuala Lumpur: EQA)

[17] Yin C Y Ali W S W and Lim Y P 2008 Journal of Hazardous Materials 150 413 – 418

[18] Li Y C Min X B Chai LY Shi M Q Tang C J Wang Q W Liang Y J Lei J and Liyang W J 2016 Journal of Environmental Management 181 756 – 761

[19] Zhen G Lu Xueqin Cheng X Chen H Yan X and Zhao Y 2012 Journal of Construction and Building Materials 30 675 – 681

[20] Chindaprasirt P Sinsiri T Napia C and Jaturapitakkul C 2013 Indian Journal of Engineering & Material Sciences 20 405 – 414

[21] Phenrat T Marhaba T F and Rachakornkij M 2004 Songklanakarin Journal of Science Technology 26 (1) 65 – 75