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SOLIDIFICATION OF WATER TREATMENT SLUDGE (WTS) BY CALCIUM CARBONATE POWDER (CCP)

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Graphical abstract

Abstract

Water treatment sludge (WTS) is a problematic waste produced from water treatment processes. WTS contains high in organic (e.g. nutrients) and inorganic (e.g. heavy metals) pollutants. There are many treatments of sludge. Current treatments of sludge are either by chemical, physical or biological treatments. However, the treatments require high energy level and expensive. Therefore, solidification method is introduced since the production of WTS is increasing. Solidification able to transform the physical forms of the sludge and depends on the type of binder used. In this study, calcium carbonate powder (CCP) was introduced as a binder to solidify WTS. The objectives of this study are to investigate the potential of CCP as binder in solidifying WTS and to obtain the optimum percentage of CCP as cement replacement material to solidify WTS. CCP was used to replace Ordinary Portland Cement (OPC) at 10%, 20%, 30% and 40%. The solidified WTS was cured under water curing for 1, 3, 7 and 28 days. The effectiveness of using CCP as binder to solidify WTS was evaluated based on the compressive strength values. Results showed that the compressive strength of solidified WTS increased with increasing curing days. However, the compressive strength of solidified WTS was reduced proportionally with the increasing percentage replacement of OPC with CCP. In conclusion, 40% CCP contains in C5 was the optimum CCP replacement percentage. The 28-day compressive strength value of C5 was 0.62 N/mm^2 and the value was exceeded the minimum allowable landfill disposal limit which is 0.34 N/mm^2.

Keywords: Water treatment sludge (WTS), calcium carbonate powder (CCP), sludge treatment, solidification method, binary blended binder, compressive strength

1.0 INTRODUCTION

Water treatment sludge (WTS) is a sludge produced from water treatment processes. WTS is sludge needs to be treated as it is considered as a problematic waste. WTS is rich in organic (i.e. nutrients) and inorganic (i.e. heavy metals) pollutants [1]. Due to this, WTS requires a proper treatment to ensure it is safely deposited to landfill.

Large production of WTS is depending on the quality of water resources [2]. High pollutants either organic or inorganic pollutants in water resources will require high amount of chemical during the treatment processes in order to treat WTS [3]. There are many methods proposed to treat WTS. The methods of treatment are either by chemical (i.e. acid, alkaline and ozone/ultrasound treatments), physical (i.e. thermal and mechanical treatment) and biological (i.e. enzyme treatment) methods [4]. The methods of treatment, however, consume high in energy as well as high in cost [5].

Solidification method is one of practical way assists in treating the sludge [6]. Solidification method is a process whereby the form of waste is changing into a more stable form. The waste will be transformed from liquid phase into solid phase during the solidification process [7]. The purpose of solidification method is to keep the hazardous waste components within the allowable limits established by regulations [8]. By improving the physical and handling characteristics of WTS, the sludge is safely dumped to a landfill. As to satisfy the safety requirement, solidification of the sludge properties has to be identified.

The solidification of sludge is largely depending on the type and material characteristic of the binder used [9]. The potential materials used in producing blended binder are such as cement by-pass dust, quarry fines, fly ash, silica fume [10-12] etc.

Blended binder was reported successfully solidifying the sludge. As shown in the study of Radzi *et al*. [13], by using two cementitious materials, pulverized fly ash and lime along with OPC, the solidification of sludge from petroleum refinery was succeed. Jain [14] had presented rice husk ash used with OPC as binder. The utilization of rice husk ash showed positive effects in the solidification method. It has reported that the utilization of rice husk ash in blended cement affected the formation of various crystalline phases during solidification. However, the potential of calcium carbonate powder (CCP) as mineral in blended binder to solidify WTS is not yet investigated.

CCP is a reactive fine white powder which can be found in limestone, marble chalk or produced artificially by combining calcium with CO_2 [15]. CCP reported can exhibit cementitious value [16]. There are some relevant advantages of using CCP as it can exert a physical filler effect on the cement hydration [17]. The advantages are in term of strength, accelerating effect and very economic benefits as compared to cement and other supplementary cementitious materials [18].

This study aims are to investigate the potential of using CCP as binder in solidifying WTS as well as to obtain the optimum percentage of CCP as cement replacement material to solidify WTS. In doing that, CCP was replaced at 10% to 40% of cement by volume as a binder to solidify WTS. The evaluation of WTS solidification is based on the compressive strength value.

2.0 MATERIALS AND METHOD

Materials used in this research is divided into three types named as Ordinary Portland Cement (OPC), calcium carbonate powder (CCP) and water treatment sludge (WTS).

OPC was supplied by local supplier and satisfied to MS 522: Part 1: 1989. CCP was supplied from a quarry belongs to Omya Sdn. Bhd. CCP is a white fine powder produced as a by-product during the manufacturing of cement. WTS was collected from Lembaga Air Perak.

X-ray fluorescence (XRF) analysis were conducted for OPC, CCP and WTS in order to determine the chemical compositions of each material respectively. Determination of water content was only conducted for WTS. Results of the analysis were as shown in Table 1. The moisture content of WTS was in the range of 0.9 – 1.0.

Table 1 The chemical compositions of OPC, CCP and WTS

Chemical compositions	OPC (%)	CCP (%)	WTS (%)
CaO	63.0	68.30	0.17
SiO_2	20.0	-	26.74
Al_2O_3	5.70	1.84	20.72
MgO	0.99	-	-
Fe_2O_3	2.90	0.07	10.36
SO_3	3.50	-	2.20
Na_2O	0.08	-	-
K_2O	1.20	-	0.74
LOI	2.63	-	-
Others	-	29.79	39.07

The quantity of OPC used was based on weight-to-weight ratio by volume of CCP replacement. Four samples were produced with partially substitution of CCP by volume into OPC in various percentages of 10% (C2), 20% (C3), 30% (C4) and 40% (C5) as shown in Table 2.

Table 2 The percentage proportions of samples

Samples	OPC:CCP	WTS (g)
C1	100:0	200
C2	90:10	200
C3	80:20	200
C4	70:30	200
C5	60:40	200

C1, control sample using 100% OPC was used to discover the influence of CCP substitution in solidifying the WTS. 200g of WTS was used for each sample and prepared in triplicate. Taken into note, 100% WTS was not evaluated for solidification purpose. This is because high water content in WTS prevents WTS to solidify itself with strength even for long time.

All the samples were cast into 50mm x 50mm x 50mm cubes for compressive strength test. All the cubes were cast in standard steel moulds. After 24 hours of casting, the samples were removed from the moulds and cured. The cubes were tested for compressive strength accordance to BS 8110: Part 2: 1985 at 1, 3, 7, and 28 days using Universal Testing Machine (UTM).

3.0 RESULTS AND DISCUSSION

The comparison between the compressive strength of solidified WTS and landfill disposal limit was done for all the results obtained. The landfill disposal limit is referred to UK landfill disposal limit which is 0.34 N/mm^2 [8]. The compressive strength of solidified WTS at 1, 3, 7 and 28 days of curing were determined to assess the potentiality of CCP as binary blended binder system in solidifying WTS. Table 3 and Figure 1 provide the experimental data and the trend for compressive strength of solidified WTS up to day-28 respectively.

Table 3 Compressive strength of solidified WTS

Samples	1-Day	3-Day	7–Day	28-Day
C1	0.77	0.99	1.26	1.43
C2	0.69	0.76	0.99	1.10
C3	0.56	0.68	0.79	0.96
C4	0.49	0.52	0.61	0.69
C5	0.40	0.45	0.56	0.62

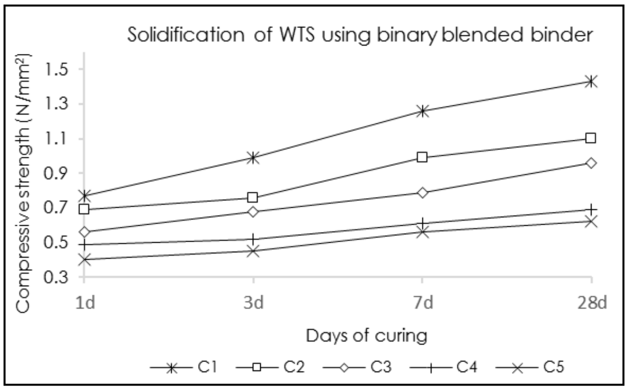

Figure 1 Solidification of WTS using binary blended binder

Table 3 and Figure 1 shows the compressive strength data obtained at 1, 3, 7 and 28 days of curing of solidified WTS using binary blended binder. The results seemed to be related to the content of CaO, SiO_2 and H_2O in the binder materials. CaO, SiO_2 and H_2O are important compositions need for the hydration process in order to develop the Calcium-Silicate-Hydrate (C-S-H) gel [19]. The C-S-H gel is then will contribute towards the strength development. Another possible explanation for the compressive strength data obtained in Table 3 and Figure 1 is the effects of WTS itself to the performance of the developed binary blended binder. WTS contains high of silicon oxide (SiO_2), alumina oxide (Al_2O_3) and iron oxide (Fe_2O_3) as expected while determine the composition of WTS. Referred to Lan *et al*. [20], SiO_2, Al_2O_3 and Fe_2O_3 compositions in WTS however can possess cementitious properties when react with $Ca(OH)_2$. $Ca(OH)_2$ is a compound that contribute slightly to the strength due to the weak link in the cement paste from a durability point of view. With the existence of SiO_2, Al_2O_3 and Fe_2O_3 compositions in WTS, the limitation in strength development throughout curing periods was overcome although the main purpose of developing the binary blended binder was to solidify WTS. The use of CCP may be linked to the behaviour problem in solidifying WTS. The compressive strength values of solidified WTS were reduced as the percentage proportions of CCP in samples increased. Although, these results differ from some published studies [16, 21, 22], the results consistent with those that higher limestone content lead to lower compressive strength [17,23]. Thus, the presence of large quantities of CCP decreases compressive strength.

In addition, this research confirms that the use of OPC alone as a solidifying agent yielded the best results in solidifying WTS [7]. The compressive strength of the solidified WTS were 0.77 N/mm^2, 0.99 N/mm^2, 1.26 N/mm^2 and 1.43 N/mm^2 at 1, 3, 7, and 28 days of curing respectively.

This is followed by sample C2, C3, C4, and C5. The compressive strengths achieved by these samples were higher than the allowable landfill disposal limit that is 0.34 N/mm^2. Thus, all developed binary blended binders in this study can be considered successfully solidify WTS. However, C5 will be more cost-effective as well as more environmental friendly in solidifying WTS. Hence, 40% CCP in C5 is considered as the optimum mix proportion used to develop binary blended binder system in order to solidify WTS. There is, therefore, CCP is a very potential material for binary blended binder application in solidification method to treat WTS.

4.0 CONCLUSION

In general, the findings conclude that the compressive strength of solidified WTS increased with increasing curing days. It was also shown that the use of CCP in developed binary blended binder system may be linked to the behaviour problem in solidifying WTS whereby the compressive strength of solidified WTS were reduced as the percentage proportions of CCP in samples increased. In addition, the use of OPC alone as a solidifying agent in this research yielded the best results in solidifying WTS. In summary, C5 which contains 40% CCP was considered as the optimum mix proportion in order to develop new binary blended binder system for solidification method to treat WTS.

As for recommendation, an assessment on the effectiveness of CCP as a new developed binary blended binder system needs to be evaluated. A further research could assess on the morphology analysis and the leach of heavy metals of the treated waste using CCP as a binder.

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