Pertanika J. Sci. & Technol. 23 (2): 193 - 205 (2015)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Incinerated Domestic Waste Sludge Powder as Sustainable Replacement Material for Concrete

Kartini, K.*, Dahlia Lema, A.M., Dyg. Siti Quraisyah, A.A., Anthony, A.D., Nuraini, T. and Siti Rahimah, R.

Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

ABSTRACT

Sludge is an unavoidable product of wastewater treatment that creates problems of disposal. Increasingly, strict environmental control regulations have resulted in limitations on sludge disposal options.Disposal by incineration has been found to be a good option. In this research, application of domestic waste sludge powder (DWSP) was used as cement replacement in concrete mix. This study utilised replacement of 3 %, 5 %, 7 %, 10 % and 15 % by weight of OPC with water binder (w/b) ratio of 0.60, 0.55 and 0.40 for Grade 30, Grade 40 and Grade 50 respectively. The performance of DWSP concrete in terms of its compressive strength, water absorption, water permeability and Rapid Chloride Ion penetration were investigated. All values of compressive strength for DWSP concrete were lower compared to the OPC control, and the strength decreased as the percentage of replacement with DWSP increased for Grade 30 and Grade 50, except for Grade 40 at replacement of 7 %. Meanwhile, water absorption and water permeability for the DWSP concrete increased as the replacement increased. Overall, with further research in producing quality DWSP, the potential of using this waste as a cement replacement material is very promising.

Keywords: Domestic Waste Sludge Powder, compressive strength, water absorption, water permeability, Rapid chloride Ion penetration

INTRODUCTION

In recent decades, disposal of dry sludge have been an important problem of sewage treatment plants due to environmental restrictions. The material is not usually permitted to be buried in soil or used as agricultural fertiliser because of its high heavy metal content. For highly urbanised

Article history:
Received: 21 February 2014
Accepted: 23 June 2014

E-mail addresses:
ce_kartini2002@yahoo.com (Kartini, K.),
DahliaLemaM@yahoo.com (Dahlia Lema, A. M.),
Q_raisyahdsq89@yahoo.com.my (Dyg. Siti Quraisyah, A. A.),
crnls_anthony@yahoo.com (Anthony, A. D.),
nanie_nuraini@yahoo.com (Nuraini,T.),
emarosseli@yahoo.com (Siti Rahimah, R.)
*Corresponding Author

ISSN: 0128-7680

cities, sludge disposal by land filling might not be appropriate due to limitation of land. Some investigations on concrete mix designs showed that the properties of sludge have been undergoing changes through technological advancement (Zeedan, 2010; Cyr *et al*., 2007; Monzo *et al*., 2003). The increasing demand for cement and concrete can be made possible with the introduction of cement replacement. The use of dry sludge as an alternative for cement replacement as a means of waste disposal and resource recovery for sustainable and inexpensive raw materials should be looked into. It was reported that the volume of sludge in Malaysia is expected to rise to 7.0 million m^3 annually with a typical wastewater treatment plant (WTP) producing about 200,000 m^3 of sludge per day (Chiang *et al*., 2009). Abdul Jalil (2010) reported that for Kuala Lumpur itself, the per capita domestic waste generated was approximately 0.8-1.3 kg per day, with 50 % of the waste being organic as cited in Bavani and Phon (2009). With these statistics, it is expected that large volumes of dry sludge produced and finding areas for disposal will be a problem. Increasingly strict environmental control regulations have also resulted in limitations on sludge disposal options. Disposal by incineration has been found to be a good option. The product of incineration will be utilised or recycled into building and construction materials, resulting in economical, technological, ecological and sustainable advantages. This will dramatically reduce or overcome the current sludge disposal problem.

Reuse of water treatment sludge has received considerable attention recently, and the reuse of sludge in the production of construction materials has been thoroughly investigated. According to Chiang *et al*. (2009) and Deng and Chih (2001), dried sludge could be used as brick-making material. Matar (2008) commented that not more than 10 % of sludge can be added to make concrete Grade 40; any more will cause compressive strength to drop.Monzo *et al*. (2003) reported that incinerating the sludge up to 800°C can produce an amorphous SSA, while Chih *et al*. (2003) stated that sludge ash collected after incineration could be used as brick-making material. Fontes *et al*. (2004) in their investigation on the potential use of sewage sludge ash suggested that the sludge should be burnt to a temperature of 550°C for 3 hours for it to be used as cement replacement, while Deng and Chih (2001) revealed that the performance of sludge concrete is related to the amount of sludge ash added to the mixture. An increase in the amount of sludge in the internal pores of cement also increases the percentage of water absorption. A study conducted by Jamshidi (2011) on sludge concrete with w/b ratio between 0.45 and 0.55 showed that a 5 % addition of sludge in concrete gave the lowest water absorption, beyond which water absorption increased. Another form of sludge utilisation was the production of lightweight concrete aggregate from a mixture of clay and sludge (Chen *et al*., 2006). Preliminary results from Tay (1986) showed that sludge ash could also be used as filler in concrete and as brick-making material. Knowing the potential of this dry sludge as building material, a study was initiated to investigate the potential use of the locally available dried wastewater sludge as partial replacement for cement in Grade 30, Grade 40 and Grade 50 concrete in terms of its compressive strength and durability index performance.

METHODOLOGY

Materials

Domestic Waste Sludge Powder (DWSP) was produced from sludge obtained from KLIA Wastewater Treatment Plant. The wet digested sludge cake with its odour of tar was allowed to dry under the hot sun for a week to remove some of the moisture, and later burnt under uncontrolled burning in a ferrocement furnace for 72 hours. This was to ensure that some of the water in the sludge was removed so as not to add to the total amount of water required (i.e. water binder ratio; w/b) in the concrete mix. The dry sludge cakes of about 5 kg were ground using the Los Angeles (LA) Abrasion machine. Inside the LA drum, there were 45 ball bearings, each of diameter 25 mm. The drum was rotated at 5000 revolutions using an electric motor at a speed of 25.7 rpm (revolutions per minute). After grinding, in ensuring fineness, the crushed dry sludge was sieved through a 90 µm sieve in order to produce DWSP. The fineness of 100 gram DWSP passing a 90 µm sieve was 25 %. Fig.1 shows the process of obtaining the DWSP. Other materials used in the concrete mixture were crushed stone granite of 20 mm maximum size and mining sand passing a 5 mm BS 410 sieve.

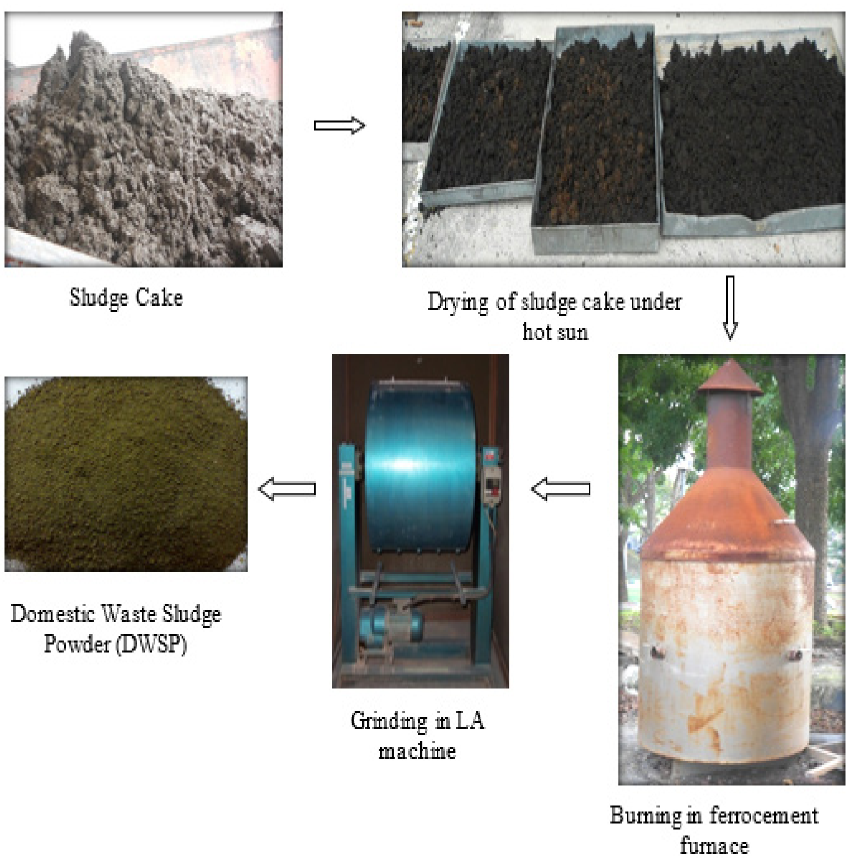

Fig.1: Process involved in the production of Domestic Waste Sludge Powder (DWSP)

The chemical composition test on DWSP and OPC was conducted and tabulated as shown in Table 1. The table shows that the oxide compositions of OPC confirmed the results obtained from the Energy Dispersive X-ray Spectroscopy (EDAX) test conducted (Fig.2). The OPC constituted of calcium oxide (CaO) and silicon dioxide (SiO_2) of 65 % and 21 %, respectively. The alkali expressed as sodium oxide (Na_2O) was 0.05%. While, SiO_2 in DWSP was 19.4 % and CaO was 5.93 %. Silicate is the main component of sludge; it is what makes sludge applicable for use as raw material in ceramic production. Sulphur trioxide (SO_3), that is, gypsum was quite high in DWSP, i.e. 8.53 %. This SO_3 is used to retard quick setting in cement. Phosphorous pentoxide (P_2O_5) content is quite high (8.77 %), and the amount is the critical factor limiting the feed rate as cement quality is adversely affected if its concentration in cement is too high. It is to be noted that sludge components vary as they depend on local circumstances and the treatment methods.

TABLE 1: Chemical Composition of DWSP and OPC

Chemical Composition	Content in %	
	DWSP	OPC
Silicon dioxide (SiO_2)	19.4	21.38
Aluminium oxide (Al_2O_3)	6.74	5.6
Ferric oxide (Fe_2O_3)	5.86	3.36
Sulphur trioxide (SO_3)	8.53	N/A
Calcium oxide (CaO)	5.93	64.64
Magnesium oxide (MgO)	0.93	2.06
Potassium oxide (K_2O)	1.69	N/A
Sodium oxide (Na_2O)	0.10	0.05
Phosphorous pentoxide (P_2O_5)	8.77	N/A
Titanium oxide (TiO_2)	0.50	N/A
Manganic oxide (Mn_2O_3)	0.06	N/A

Mix Proportion

The mix design adopted for the preparation of the concrete specimens in this research was based on methods used by the British Department of Environment (1986). Table 2 gives details of the series of the mix proportion prepared.

In this present study, six (6) series of concrete specimens were prepared based on replacement level of 0 %, 3 %, 5 %, 7 %, 10 % and 15 % of DWSP to the OPC by weight. These mixes are designated as OPC, DWSP3, DWSP5, DWSP7, DWSP10 and DWSP15, representing concrete made of OPC plain, 3 %, 5 %, 7 %, 10 % and 15 % of DWSP to the OPC respectively. As the grade of concrete varies, each series is composed of a different w/b ratio of 0.4, 0.55 and 0.6, with cement content of 475 kg/m^3, 350 kg/m^3 and 320 kg/m^3 respectively. The mixes of 100 % OPC were used as control reference. All the requirements for making the specimen were in accordance with BS EN 12390-1:2000.

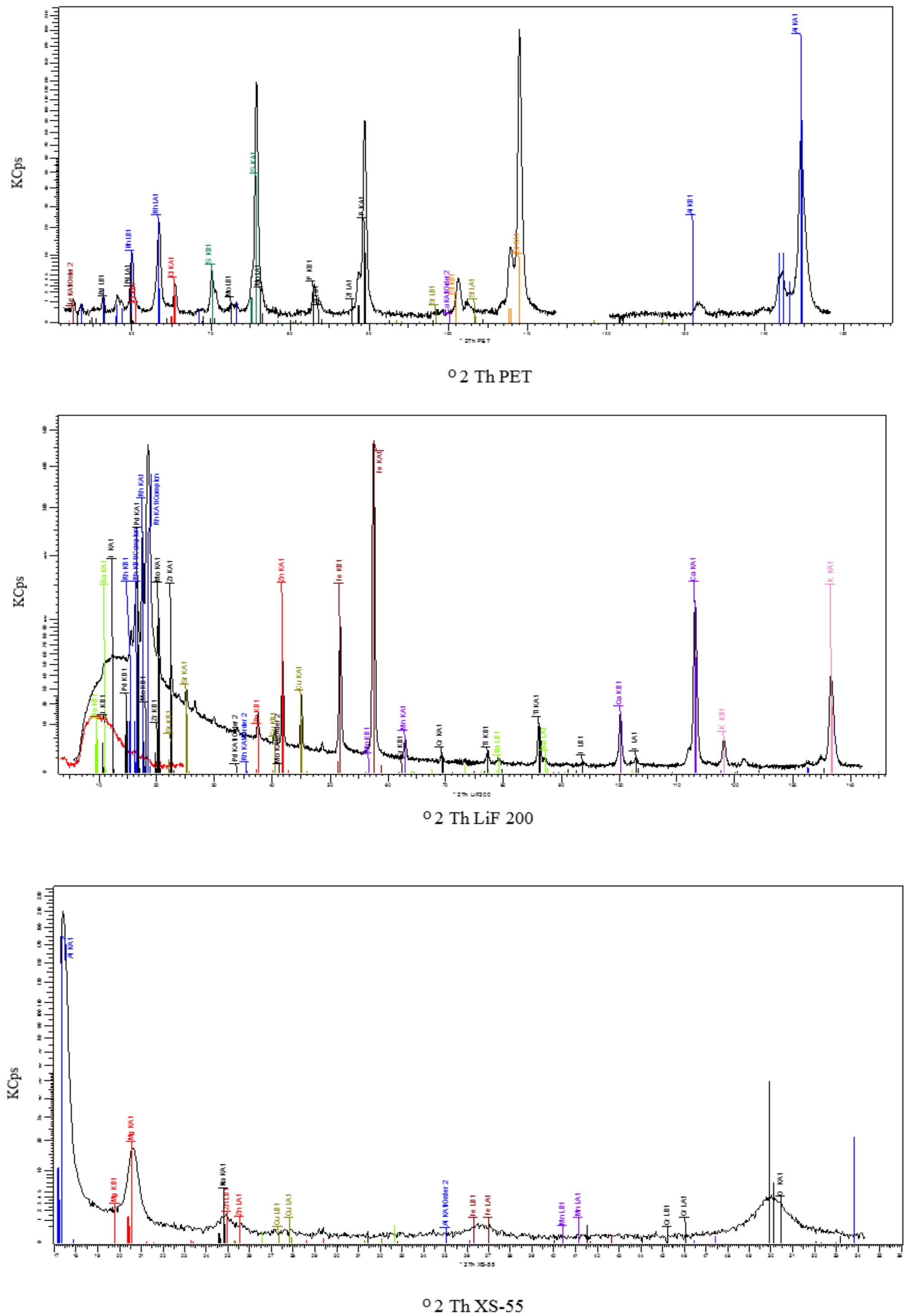

Fig.2: Energy Dispersive X-ray Spectroscopy (EDAX) test

TABLE 2 : Mixture Proportion of DWSP concrete

Mixes	Concrete Grade	Mass per Unit Volume of Materials (kg/m^3)					w/b
		Cement	DWSP	Water	Aggregate		
					Fine	Coarse	
OPC	30	320	-	190	1170	850	0.6
DWSP3		310	10	190	1170	850	
DWSP5		304	16	190	1170	850	
DWSP7		297	23	190	1170	850	
DWSP10		288	32	190	1170	850	
DWSP15		272	48	190	1170	850	
OPC	40	350	-	190	835	980	0.55
DWSP3		340	10	190	835	980	
DWSP5		333	17	190	835	980	
DWSP7		326	24	190	835	980	
DWSP10		315	35	190	835	980	
DWSP15		298	52	190	835	980	
OPC	50	475	-	190	645	1095	0.40
DWSP3		460	15	190	645	1095	
DWSP5		450	25	190	645	1095	
DWSP7		440	35	190	645	1095	
DWSP10		430	45	190	645	1095	
DWSP15		405	70	190	645	1095	

Test Methods

Several tests were performed to determine the chemical composition, fineness of DWSP and hardened DWSP concrete. For hardened concrete, the compressive strength of 100 mm cube specimens was conducted based on BS EN 12390-3:2000. The water-cured specimens were tested at the age of 7, 28 and 60 days.

For determination of the durability properties of the concrete specimens, the water absorption test was conducted on the cylindrical specimens of 50 mm in diameter by 100 mm height. The specimens were oven-dried to constant mass at 105 ± 5ºC for 72 ± 2 hours and then stored in air-tight containers as stipulated in BS 1881-122:2011. The specimens were water-cured until ages of 28 and 60 days before testing, and the specimens were weighed before the immersion in water for 30 minutes, 60 minutes, 120 minutes and 240 minutes. To determine the water permeability of the concrete, the test was based on BS EN 12390-8:2000. In Rapid Chloride Penetration Test (RCPT), three (3) water-cured specimens of size 100 mm x 50 mm dia. cylinder from each selected mix were tested for chloride ion penetration at 28 and 60 days age of testing. The test was conducted according to the standard procedure of ASTM C1202: 1997.

Table 3 summaries the types of test conducted in the research and also the numbers of specimens prepared for each test.

TABLE 3: Types of test conducted and number of specimens prepared for OPC and DWSP Concrete

Mixes	Test Conducted and Number of Specimens								
	Compressive Strength Test (Cube –100 x 100 x 100 mm)			Water Permeability Test (Cylinder –150 mm dia. x 150 mm)		Water Absorption Test (Cylinder –50 mm dia. x 100 mm)		Rapid Chloride Penetration Test (Cylinder –50 mm dia. x 100 mm)	
	Curing Period (Days)								
	7	28	60	28	60	28	60	28	60
OPC	5	5	5	5	5	5	5	3	3
DWSP 3	5	5	5	5	5	5	5	3	3
DWSP 5	5	5	5	5	5	5	5	3	3
DWSP 7	5	5	5	5	5	5	5	3	3
DWSP 10	5	5	5	5	5	5	5	3	3
DWSP 15	5	5	5	5	5	5	5	3	3
		90		60		60		36	

RESULTS AND DISCUSSION

Compressive Strength

Table 4 shows the results of compressive strength and the percentage remained of the compressive strength obtained for different concrete grades, mixes and ages of water curing. For Grade 30 concrete, the 28-day strength of all the DWSP concrete was below the control concrete (OPC) for replacement of 3 % to 15 %. It also shows that as period of curing increased, strength also increased. This is true as there is still reaction of the organics sludge with cement that occurs at a slow rate.

TABLE 4 : Compressive strength of OPC and DWSP concretes of various mixes

Grade	w/b	Compressive Strength (N/mm^2)			Percentage Remained Comp. Strength (%)		
		7 days	28 days	60 days	7 days	28 days	60 days
30	0.6	-	31.77	35.28	-	100.0	100.0
		-	26.33	30.49	-	82.9	86.4
		-	25.28	27.35	-	79.6	77.5
		-	21.76	24.40	-	68.5	69.2
		-	20.52	22.81	-	64.6	64.7
		-	18.88	20.23	-	59.4	57.3

TABLE 4 : (Cont)

40	0.55	20.63	40.24	45.54	100.0	100.0	100.0
		18.33	31.90	33.96	88.9	79.3	74.6
		22.77	37.76	40.18	110.4	93.8	88.2
		26.59	42.75	44.61	128.9	106.2	2.04
		12.63	27.46	29.55	61.2	68.2	98.0
		9.33	23.84	23.03	45.2	59.2	50.6
50	0.40	46.1	53.5	67.6	100.0	100.0	100.0
		18.1	27.3	28.4	39.3	51.0	42.0
		14.6	21.8	21.9	31.7	40.7	32.4
		7.93	16.1	20.6	17.2	30.0	30.5
		-	4.9	8.6	-	9.2	13.0
		-	0.99	3.1	-	2.0	5.0

For concrete Grade 40, it can be seen that the compressive strength of DWSP concretes decreased compared to OPC control concrete, and increased as the period of curing prolonged. However, increase in the percentage of replacement in the DWSP concrete from 5% to 7% resulted in increase in strength, beyond 7 % the compressive strength reduces. This might be because by replacing more than 7 % of cement with sludge powder, the cement reaction was lower in the concrete mass due to the decrease of the CaO ratio as a result of higher replacement of DWSP. Besides this, the oxide composition of SiO_2 in DWSP was only 19.4 % (low quality of sludge), which was much lower than OPC (21.38 %) and thus, produced slow setting, hence low strength. In Grade 50 concrete, the compressive strength of DWSP showed very low strength. In fact, with 10 % and 15 % replacement, total collapse was at 7-days' strength, while prolong curing (28 days and 60 days) gave a very small increase in strength. This might also be due to a high content of SO_3 in DWSP (8.53 %), which retarded the quick setting in cement, thus slowing the rate of hydration taking place in the matrix during the fresh state due to a high content of SO_3. A study by Cyr *et al*. (2007) on the hydration time of sludge ash with respect to compressive strength showed that as the amount of sludge ash increased, strength was reduced and at early hydration time (1 day), strength was much lower compared to longer hydration time (28 days). The high amount of sludge in the concrete mix delayed the setting time and subsequently, the concrete mechanical properties were reduced significantly due to the presence of organic material in sludge. The results obtained from this study were also in agreement with a study conducted by Matar (2008), in which the compressive strength of Grade 40 concrete decreased when the percentage of sludge content was 10 % or more.

Water Absorption

Table 5 records the percentage by weight of water absorbed for each concrete mix for Grade 30, Grade 40 and Grade 50 for four (4) hours of immersion. Based on the results obtained for each concrete grade, water absorption for the control concrete (OPC) taken at 28 days curing were 4.11 %, 4.18 % and 4.20 %, respectively. Neville (2008) revealed that concrete can be considered good concrete if the percentage of water absorption was below 10 % by mass of concrete.

For the DWSP concrete, it can be seen that as the percentage of replacement of OPC with DWSP increased, the percentage water absorption for all mixes also increased. For Grade 30, Grade 40 and Grade 50 concretes taken at 28 days of curing, the percentage of water absorption ranged between 4.30 % and 4.80 %, 4.35 % and 4.92 % and 4.40 % and 4.90 % respectively. The results obtained also confirmed the finding of Valls *et al*. (2004), which showed that absorption capacity increased with an increase in sludge content. This might be due to capacity to hold water increase together with a certain increase in the number of cavities inside the concrete. A study by Jamshidi *et al*. (2011) on sludge concrete with w/b ratio between 0.45 and 0.55 showed that a 5 % addition of sludge in concrete gave the lowest water absorption, beyond that water absorption increased. A study by Deng and Chih (2001) revealed that the ability of the concrete mixture was apparently related to the amount of sludge ash added to the mixture. They further commented that as the adhesivity of the mixture decreased, the internal pore of the cement increased when the mixture contained a high percentage of sludge (Deng & Chih, 2001). As a result, the quantity of absorbed water increased.

TABLE 5 : Water absorption characteristics of OPC and DWSP concretes

Mixes	Concrete Grade	w/b	Absorption, %	
			28 days	60 days
OPC	30	0.6	4.11	3.85
DWSP3			4.30	4.11
DWSP5			4.52	4.34
DWSP7			4.64	4.46
DWSP10			4.75	4.61
DWSP15			4.80	4.67
OPC	40	0.55	4.18	3.85
DWSP3			3.73	3.52
DWSP5			4.51	4.21
DWSP7			4.61	4.44
DWSP10			4.87	4.50
DWSP15			4.92	4.75
OPC	50	0.40	4.20	3.98
DWSP3			4.40	4.12
DWSP5			4.56	4.20
DWSP7			4.66	4.31
DWSP10			4.73	4.63
DWSP15			4.90	4.80

On the other hand, prolonged curing to 60 days resulted in a lower degree of water absorption. This might be due to the fact that proper hydration had taken placed, which over time, decreased the number of pores. However, all the mixes with the replacement of sludge could still be considered as having average water absorption value as the value was within the range of 3-5 % as stipulated in BS 1881: Part 122: 2011.

Water Permeability

Fig.3 shows the depth of penetration of water into the concrete mixes taken at 28 days and 60 days of water curing. Fig.3 also shows that 3 to 7 % of DWSP in concrete gave lower depth of penetration compared to OPC control mix concrete for Grade 40 concrete. The reason might be that DWSP material occupied the empty space in the pore structure and substantially reduces the permeability of the concrete. This resulted in reduction in the porosity of the concrete and, subsequently, the pores. This is in accordance with a study by Sandrolini and Franzoni (2003), in which they commented that porosity increased with an increase of sludge content and over periods of time (age of concrete), the number of pores decreased, thus reducing the depth of water penetration. However, further increase in the percentage of replacement with DWSP resulted in higher depth of water penetration into the concrete compared to the control OPC concrete. This is in line with Valls *et al*. (2005), who reported that higher concentration of sludge resulted in high porosity of concrete, where the pores were interconnected and contributed to the transport of fluids through the concrete.

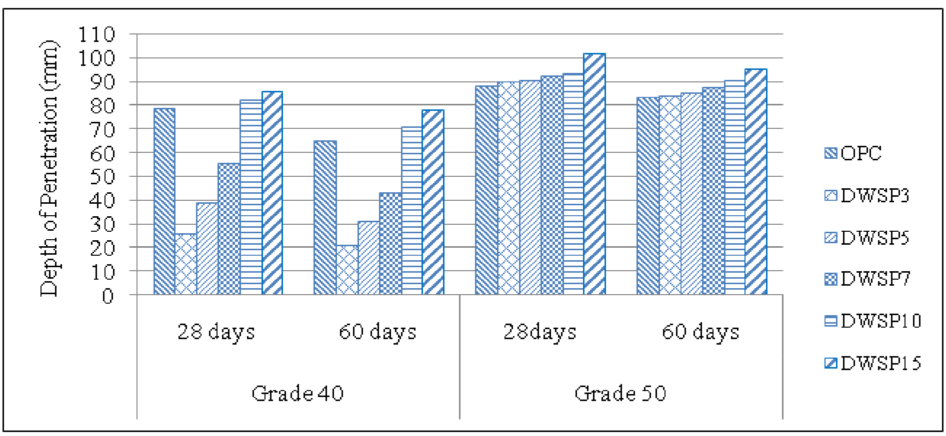

Fig.3: Depth of Penetration of water in OPC and DWSP concretes

Fig.3, which shows results for Grade 50 concrete, reveals that the depth of penetration for DWSP concrete for all series was very high compared to the control (OPC) concrete. This was again in accordance with the finding of Valls *et al*. (2005), which showed that the internal pores of the cement matrix increased when the mixture contained a high percentage of sludge. Thus, the more permeable the concrete, the lower will be its resistance to deterioration; therefore, it can be said that the durability of concrete decreases with increased in DWSP in concrete.

Chloride Ion Penetration

Table 6 shows the coulomb charge of the DWSP concrete of Grade 40 taken at age of 60 days. Reference to ASTM C1202: 1997 in determining the degree of chloride permeability (charge passed) of the concrete is also shown in the table. These coulomb charge values were obtained when the specimens were subjected to 60 V applied DC voltage for 6 hours.

TABLE 6 : Coulomb Charge of OPC and DWSP concretes

Mixes	Concrete Grade	w/b	Chloride Permeability (Coulomb)			
			28 days	ASTM C1202 (1997)	60 days	ASTM C1202 (1997)
OPC	40	0.55	4326	High	2775	Medium
DWSP3			3510	Medium	1693	Low
DWSP5			2812	Medium	1403	Low
DWSP7			1940	Low	1135	Low
DWSP10			1955	Low	1329	Low
DWSP15			2202	Medium	1477	Low

The table shows that the OPC concrete has high charge passed values at the age of 28 days and the values obtained from the OPC concrete with reference to ASTM C1202: 1997, indicated a rather high chloride penetrability characteristic, while a prolonged curing period resulted in the charge coulombs for the concrete being improved. However, for the DWSP concretes, it was seen that with the increase of sludge up to 7 % resulted in the charge passed value being reduced. Increasing the percentage of sludge beyond 7 % in the concrete resulted in an increase in the charge passed, even though according to ASTM C 1202: 1997, it still gave low-to-medium chloride permeability.

CONCLUSION

From the investigation carried out, increasing the replacement of OPC with DWSP in the concrete mixes resulted in lower compressive strength. The water absorption values of DWSP concrete were higher than the OPC control concrete.However, all the mixes with the replacement of sludge could still be considered as having average water absorption value as the values were still within the range of 3-5 % as stipulatedin BS 1881: Part 122: 2011.

OPC control concrete was more permeable than the DWSP concretes for Grade 40concrete; however, for Grade 50, the DWSP concrete gave higher depth of penetration (more permeable). The resistance to chloride ion penetration of concrete as measured by the charge coulomb drastically enhanced resistance to chloride permeability with incorporation of DWSP up to15 %. This suggested that the presence of DWSP (Grade 40) resulted in lower coefficient of permeability.

Overall, there is potential for using DWSP as partial cement replacement. However, more detailed research should be conducted to yield methods for producing quality powder.

REFERENCES

Abdul Jalil, M. D. (2010). Sustainable development in Malaysia. A case study on household waste management. *Journal of Sustainable Development, 3*(3), 91-102.

ASTM C1202: 1997. *Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*.

Bavani, M., & Phon, L. L. (2009). Using worms to reduce organic waste, DBKL to embark on a pilot project soon. Saturday Metro, 2009, Dec 5.

British Standard Institution *BS 1881-122:2011*. *Testing Concrete – Method for Determination of Water Absorption,* London.

British Standard Institution *BS 410-1:2000. Test Sieves. Technical requirements and testing. Test sieves of metal wire cloth*, London.

British Standard Institution *BS EN 12390-1:2000. Testing Hardened Concrete. Shapes, dimensions and other requirements for specimen and mould.*

British Standard Institution *BS EN 12390-3:2000. Testing Hardened Concrete. Compressive Strength of Test Specimen*.

British Standard Institution,*BS EN 12390-8:2000. Testing Hardened Concrete. Depth of penetration of water under pressure.*

Chen, C. H., Chiou, I. J., Wang, K. S., & Lin, Y.T (2006). Lightweight aggregate made from sewage sludge and incinerated ash. *Waste Management, 26*, 1453–1461.

Chiang, K. Y., Chou, P. H., Hua, C. R., Chien, K. L., & Cheeseman, C. (2009). Lightweight bricks manufactured from water treatment sludge and rice husks. *Journal of hazardous materials, 171*(1), 76-82.

Chih, H. W., Deng, F. L., &Pen, C. C. (2003). Utilization of sludge as brick materials. *Advances in Environmental Research, 7,* 679–685.

Cyr, M., Coutand, M., & Clastres, P. (2007). Technological and environmental behaviour of sewage sludge ash (SSA) in cement-based materials. *Cement and Concrete Research, 37*(8), 1278-1289.

Deng, F. L., & Chih, H. W. (2001). Use of sewage sludge ash as brick material. *Journal of Environmental Engineering,127*(10).

Department of Environment (DOE), (1986). Design of Normal Concrete Mixes. *BRE Publication*, United Kingdom.

Fontes, C. M. A., Barbosa, M. C., Toledo, R. D., & Goncalves, J. P. (2004). Potentiality of sewage sludge ash as mineral additive in cement mortar and high performance concrete. Use of Recycled materials in Buildings and Structures, Barcelona, pp.1-10.

Jamshidi, M., Jamshidi, A., & Mehrdadi, N. (2011). Application of sewage dry sludge in concrete mixtures. *Asian Journal of Civil Engineering (Building and Housing),13*(3), 365-375.

Matar, M. (2008). Use of wastewater sludge in concrete mixes. Master of Science in Design and Rehabilitation of Structures, the *Islamic University of Gaza*.

Monzo, J. P., Borrachero, J., & Girbes, M. V. (2003). Reuse of sewage sludge ashes (SSA) in cement mixtures: The effect of SSA on the workability of cement mortars. *Waste Management, 23,* 373-381.

Neville, A. M. (2008). *Properties of concrete, 4th Edition*. ISBN 978-0-582-23070-5, Prentice Hall, Pearson Education Limited.

Sandrolini, F., & Franzoni, E. (2003). Waste wash water recycling in ready-mixed concrete plants. *Cement and concrete research, 31*(3), 485-489.

Tay, J. H. (1986). Potential use of sludge ash as construction material. *Resources and Conservation, 13*, 53-58.

Valls, S.,Yague, A., Vazquez, E., & Albareda, F. (2005). Durability of concrete with addition of dry sludge from waste water treatment plants. *Cement and Concrete Research, 1064-1073*.

Valls, S., Yague. A., Vazquez. E., & Mariscal, C. (2004). Physical and mechanical properties of concrete with added dry sludge from a sewage treatment plant. *Cement and Concrete Research, 34,* 2203-2208.

Zeedan, S. R. (2010). *Utilizing new binder materials for green building has zero waste by recycling slag and sewage sludge ash*. Tenth International Conference for Enhanced Building Operations, Kuwait, ESL-IC-10-10-29.