Utilization of Cement Incorporated with Water Treatment Sludge

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ABSTRACT

This study investigated the use of water treatment sludge to replace cement in the production of paving tiles for external use. The study utilized sludge-cement replacement percentages of 10%, 20%, 30%, 40% and 50%. Produced tiles were tested for water absorption and breaking (bending) strength. Leaching of sludge metals from tiles was assessed using TCLP. The study showed that all produced tiles exhibited a water absorption ratio of around 10%. The study concluded that produced tiles, except for 50% sludge-cement replacement, comply with the breaking strength requirements of 2.8 MPa for tiles for external use. The TCLP results indicated that metal leaching from tiles is negligible.

KEYWORDS: Cement, Tiles, Water treatment sludge, Breaking strength, Absorption, Heavy metals.

INTRODUCTION

Water treatment plants that employ the conventional processes of coagulation, flocculation and sedimentation produce large quantities of sludge. Often, the volume of generated sludge can be as high as 2% of the total volume of water treated (Qasim et al., 2000). The cost of treating and disposing the sludge can be a significant part of the operating cost of a water treatment plant. In Jordan, it is estimated that a quantity of 456 tons of water treatment sludge is produced each year (MWI, 2007). As the disposal of sludge produced from water treatment plants is expensive and difficult, beneficial use options have been proposed (Townsend et al., 2001).

Options for the management of water treatment sludge have to be economically feasible and environmentally sound. Reuse of water treatment sludge has been receiving considerable attention recently. This is mainly due to the fact that this type of material, with the exception of alum and ferric sludge, does not contain pollutants that would pose threat to humans or to the environment (Florida Department of Environmental Protection, 2006). Babatunde and Zhao (2007) presented various categories of beneficial reuse of water treatment sludge. Baker et al. (2004) evaluated the potential of reusing sludge from softening water treatment for the production of construction materials in the form of gypsum and cement.

The reuse of sludge in the production of construction materials has been thoroughly investigated. Monteiro et al. (2006) investigated the incorporation of oily wastes in the production of different red ceramic products for building construction. Hytiris et al. (2004) studied the reuse of olive oil mill sludge as an additive for the development of construction materials. Cheilas et al. (2007) evaluated the reuse of sewage sludge from urban wastewater treatment plants in a mixture with cement

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and jarosite/alunite precipitates to develop new construction materials. Malliou et al. (2007) investigated the reuse of sewage sludge as an additive in order to develop new construction materials.

Chugh et al. (2006) prepared construction materials for a variety of applications using up to 95% of coal combustion by-products comprising sulfite-rich scrubber sludge and fly ash. Ferreira et al. (2003) identified and investigated nine possible applications of municipal solid waste fly ash, which were grouped in four categories and included construction materials (cement, concrete, ceramics, glass and glass–ceramics), geotechnical applications (road pavement, embankments), agriculture (soil amendment) and miscellaneous (sorbent, sludge conditioning). Lim et al. (2002) investigated the engineering properties of modified sludge from water and wastewater treatment by modifiers such as hydrated lime, loess and fly ash. Ahmadi and Al-Khaja (2001) carried out an investigation that utilized paper waste sludge as a replacement to the mineral filler material in various concrete mixes.

Research dealing with the reuse of waste and recycled materials in production of paving tiles' materials is not widely investigated. A report prepared by the Technology Assistance Partnership (1999) investigated the incorporation of mixed-color recycled glass and inorganic binders into construction materials in the form of paving tiles. The investigation involved compressive strength, flexural strength and absorption testing to assess the suitability of tiles for use. The study concluded that the average compressive strength values of tiles ranged from 14 to 27 ksi (96 MPa – 186 MPa), which is much greater than the most severe ASTM requirement of 8 ksi (55 MPa). Flexural tests resulted in moduli of rupture ranging from 1156 psi (7.97 MPa) to 4483 psi (30.9 MPa) and all tiles tested were therefore satisfactory. Absorption of water in glass tiles was generally less than 1%. The study concluded that clay and concrete tiles had water absorption of 4-5%. Additionally, tiles made with an inorganic binder referred to as fondu (calcium aluminate cement) had absorption percentages from 1 to 4%.

Reuse of sludge in the production of paving cement tiles is a subject that deserves investigation. Paving tiles that will be investigated in this study are cement tiles of the typical type used in Jordan for external use. This type of cement tiles is commonly used for sidewalks. The objective of this research is to investigate the potential of reuse of water treatment sludge in producing a construction material in the form of paving tiles. The sludge will be incorporated in the lower layer of the paving tile as a cement replacement. This will serve a dual purpose of reducing the cost of production of this construction material in addition to providing an environmentally friendly option for the disposal of the increasing amounts of sludge generated by water treatment industry.

METHODOLOGY

Materials

Sun dried ferric chloride sludge was used in this application. Sludge samples were collected from Zai drinking water treatment plant in Jordan. This plant supplies the western side of the Capital Amman with approximately 300,000 m^3/day of drinking water, and is located in the middle of the country. Complete sieve analysis for the sludge was carried out using a mechanical shaker according to ASTM C136-06. The particle size distribution of the sludge is shown in Figure (1). The sludge particle size is well-graded, and the sludge particle size used in the experiments was that passing sieve number 30 (0.60 mm). The bulk density of the sludge was 787 kg/m^3. The pH of the sludge was determined in a suspension of 20 g of sludge solids and 80 ml of deionized water (USEPA, 2001). The pH was also determined for all tile specimens prepared with sludge-cement replacement. The heavy metal content of the sludge was determined according to the standard methods for the examination of water and wastewater (APHA, 1999).

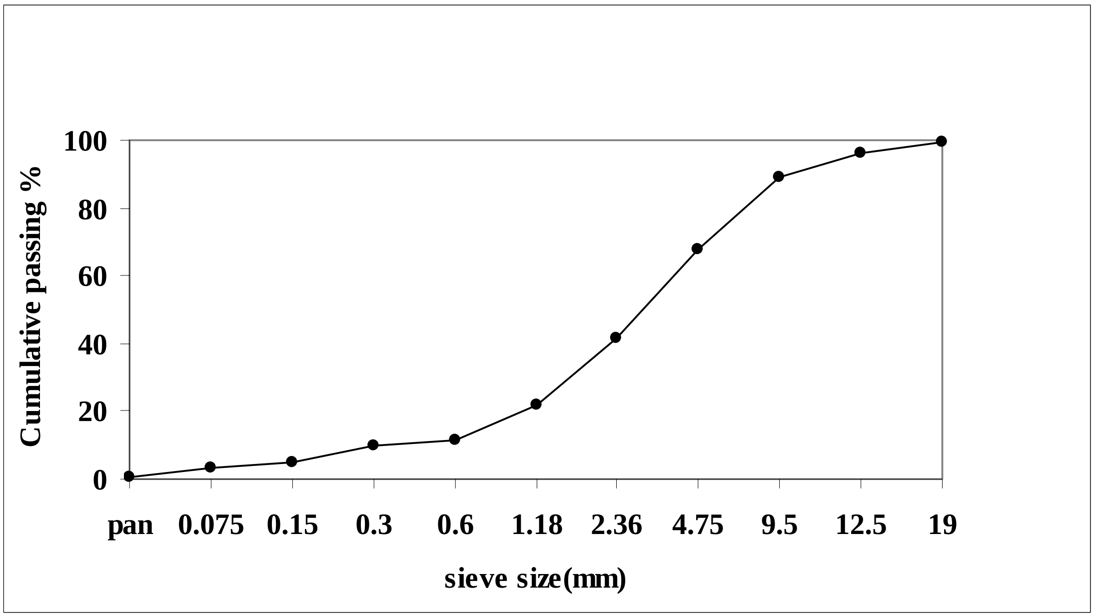

Figure 1: Particle size distribution of water treatment sludge

Pozzolanic Portland cement was used in this investigation. The cement is reported to have a specific gravity of 3.15, and meets ASTM C150-07 requirements. Sand with the grading shown in Figure (2) was used in this study. The quality and grading of sand used meet ASTM C33/C33M-08 requirements. The sand used has a unit weight of 14.8 kN/m^3, a saturated-surface dry (SSD) specific gravity of 2.29 and a percent water-absorption of 3.65.

Cement Tiles

The cement tiles used in this investigation consist of two layers. The upper layer has a thickness of 10 mm and is made of cement and quartz with a proportion of 1 to 3; in addition to 1.8 liters of water per square meter of tile. The lower layer has a thickness of 25 mm and is made of cement and sand with a proportion of 1 to 6; in addition to 7.1 liters of water per square meter of tile (JISM 2007). Manual manufacturing of cement tiles was carried out. The sludge replacement of cement was performed only in the lower layer. One square meter of tile was prepared for each percentage of sludge-cement replacement. Four tile specimens of (400mm × 400mm × 35mm) were obtained and tested from each square meter. Five percentages of cement-sludge replacement were investigated (10%, 20%, 30%, 40% and 50%). The mix needed to produce each square meter of tile required 6.25 kg of cement, 37.5 kg of sand and 7.1 liters of water.

The weathering resistance of the produced tile was determined by testing the percent water absorption. Absorption test was carried out according to BS EN 13748-2:2004. The tiles were first dried in an oven at a temperature of about 230°F (110°C) for a 24 hour period. The tiles were allowed to cool to room temperature and weighed. This weight was recorded as the dry weight. The tiles were then immersed in a tank of water at approximately room temperature and left to soak for a 24 hour period. The tiles were removed from the water and any water adhering to the upper face was removed with a moist sponge after 24 hours. The sample was then weighed again to get the saturated weight.

The breaking (bending) strength and breaking load tests were carried out according to BS EN 13748-2:2004. Each tile specimen was placed with its upper face uppermost on a transverse testing machine that has a scale accuracy of ±3% over the range of the anticipated test loads and capable of inducing 3 point bending into the sample without torsion while the load inducing bar was equidistant between the supports.

Table 1: Metal concentrations in raw sludge

Metal	Concentration (mg/L)
Cd	<0.008
Cr	<0.01
Cu	<0.01
Fe	2.68
Pb	<0.01
Mn	<0.05
Ni	<0.03
Zn	0.35

Table 2: pH of sludge-cement mixtures

Sample description	pH value
10% sludge tiles	11.5
20% sludge tiles	10.4
30% sludge tiles	10.1
40% sludge tiles	10.1
50% sludge tiles	10

The Toxicity Characteristic Leaching Procedure (TCLP) proposed by the USEPA (1992) was employed to simulate the leaching of heavy metals from tile specimens. Tile specimens with each of the slugde-cement replacement percentage were crushed. Ten grams of dry tile specimen and the appropriate extraction fluid were combined with a 20:1 ratio of liquid to dry sample into polypropylene extraction bottles. The bottles were sealed and placed on an agitator with a rotational speed of 59 rpm for a period of 18 hours. All samples in this study were ground to <0.85 mm. At the end of agitation, liquid in each bottle was separated from solid phase. The pH of the separated TCLP extracts was then measured and all extracts were acidified to pH less than 2 for long-term preservation. Heavy metal concentrations were then measured by ICP using the method described in standard methods (APHA, 1999).

RESULTS AND DISCUSSION

Sludge Characterization

Results of metal concentration measurements of raw sludge indicated that; with the exception of iron, the content of these metals in sludge is very low, as shown in Table (1). The iron content of raw sludge is attributed to the ferric chloride sludge used in this investigation.

The pH of the sludge was measured and found to be 9.2. The pH of the sludge-cement mixture was also measured and reported in Table (2). The Table shows that cement-sludge mixtures have elevated pH values. This can be attributed to the basic nature of Pozzolanic Portland cement (Derucher et al., 1998).

Water Absorption of Tiles

Commercially produced tiles are regarded acceptable depending on their facial and structural soundness, dimensional characteristics and physical properties. The most important physical requirements are water absorption and breaking strength. As a result, tiles have to satisfy both water absorption and breaking strength requirements. Tiles are classified as non-vitreous when the water absorption is above 7%, semi-vitreous when water absorption is between 3% and 7%, vitreous when water absorption is between 0.5% and 3% and impervious when water absorption is less than 0.5% (Mishulovich and Evanko, 2003).

In general, water absorption of tiles is investigated to indicate the weathering resistance of tiles and ensure its durability. The abrasion resistance and slip resistance tests are usually carried out for the upper layer of tiles. Accordingly, these tests were not conducted because this investigation dealt with cement replacement in the lower layer of tiles. More water absorption of tiles indicates less durability and resistance to the natural environment. Figure (3) shows the average percent absorption of tiles *versus* percent cement replacement. The water absorption percentage reported in the Figure is the average value of four tile specimens. The Figure indicates that all tiles produced are non-vitreous. Additionally, tiles produced with various sludge-cement replacements have a water absorption of around 10%.

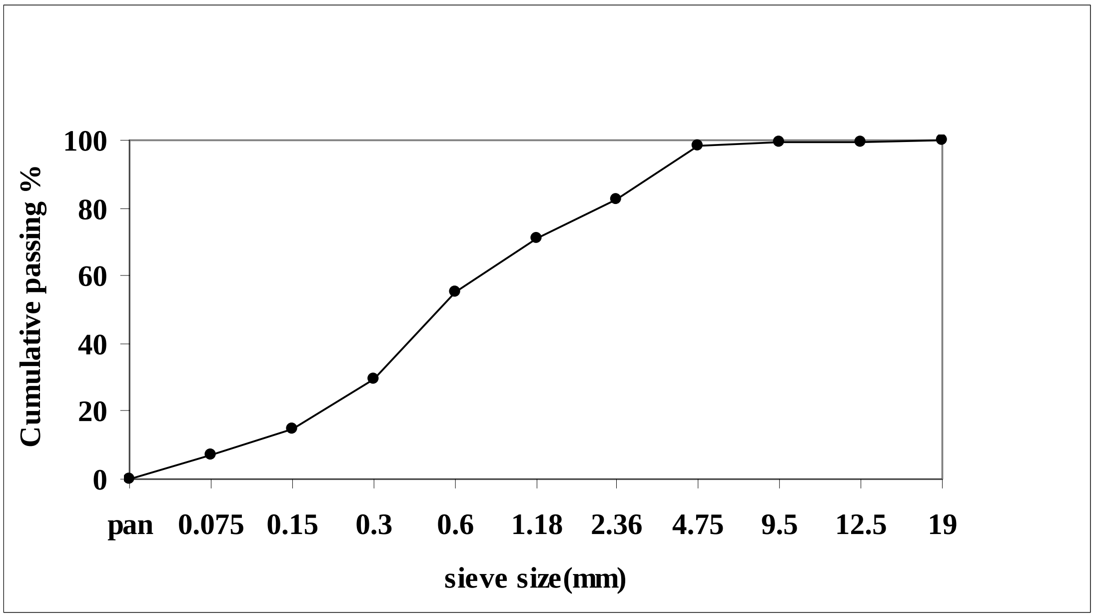

Figure 2: Particle size distribution of sand

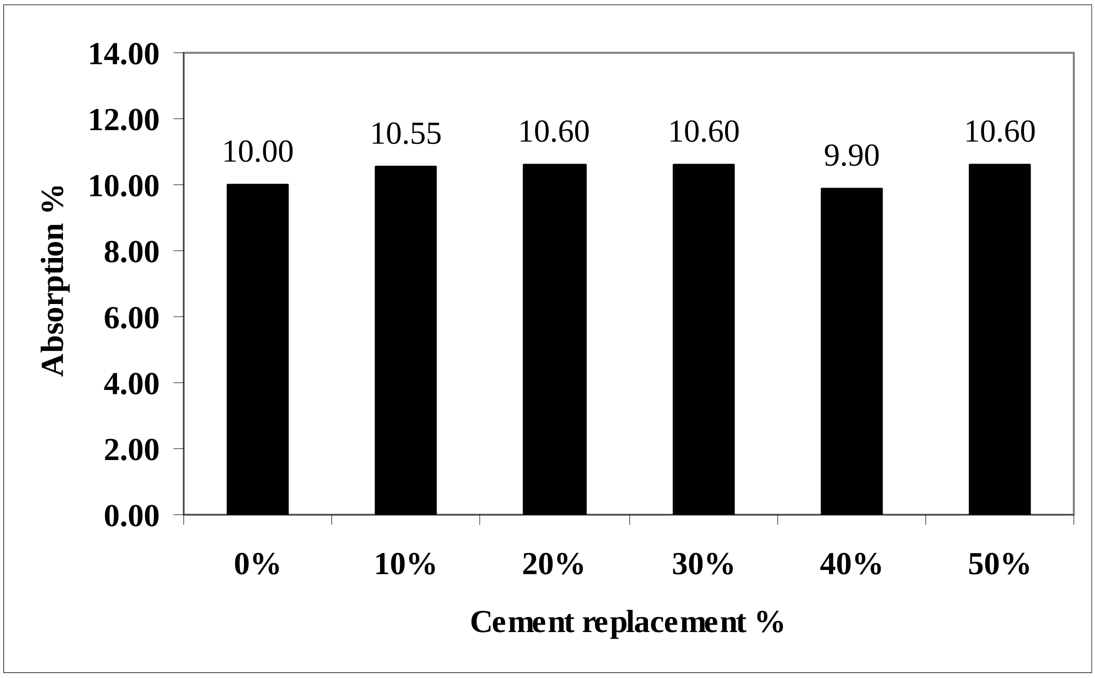

Figure 3: Average percent absorption of tiles *versus* percent sludge-cement replacement

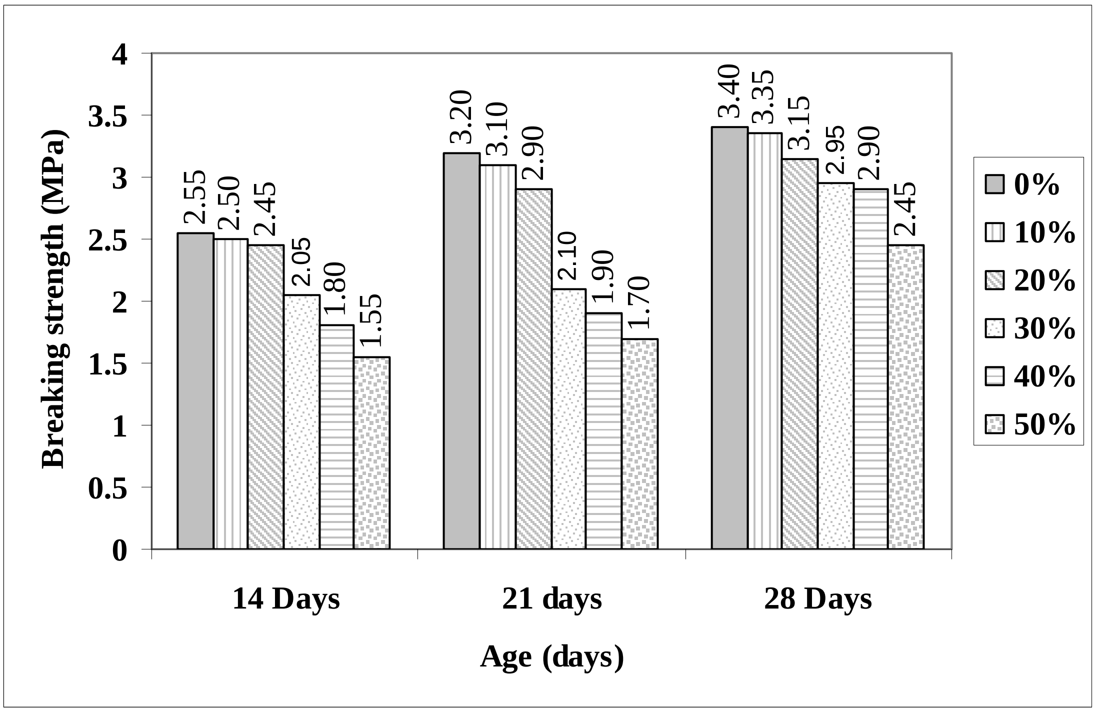

Figure 4: Average breaking strength of tiles *versus* age for all percent sludge-cement replacements

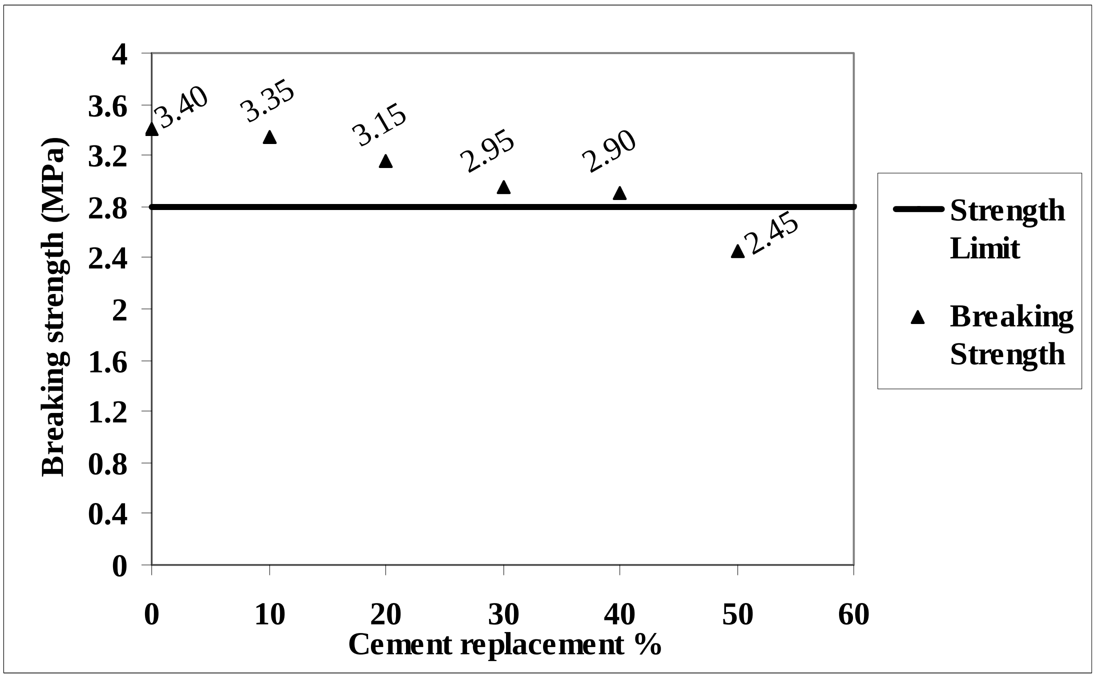

Figure 5: Comparison between breaking strength requirement (BS EN 13748-2:2004) and 28-day average breaking strength of tiles for all percent sludge-cement replacements

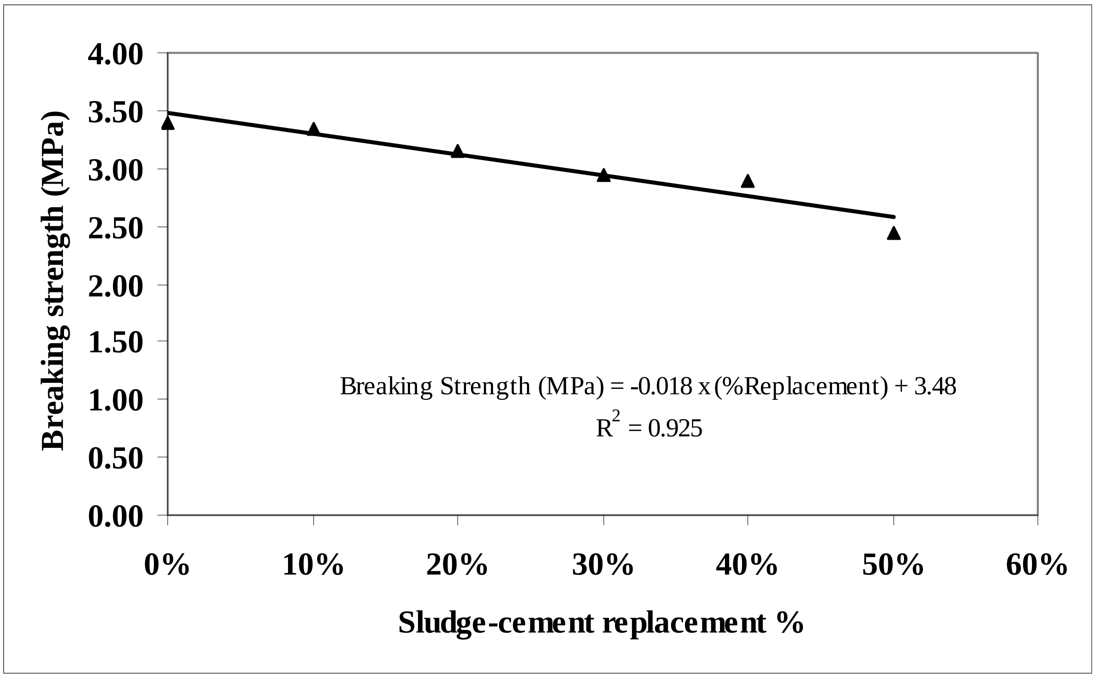

Figure 6: Average 28-day breaking strength of tiles *versus* percent sludge-cement replacements

Table 3: Metal concentrations in raw sludge, and TCLP regulatory limits along with results of heavy metals of the TCLP for different sludge-cement replacements

	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Zn (mg/L)
Sludge	<0.008	<0.01	<0.01	2.68	<0.1	<0.05	0.03	0.35
10%	<0.008	<0.01	<0.01	<0.10	<0.10	<0.05	<0.03	<0.10
20%	<0.008	<0.01	<0.01	<0.10	<0.10	<0.05	<0.03	<0.10
30%	<0.008	<0.01	<0.01	<0.10	<0.10	<0.05	<0.03	<0.10
40%	<0.008	<0.01	<0.01	<0.10	<0.10	<0.05	<0.03	<0.10
50%	<0.008	<0.01	<0.01	<0.10	<0.1	<0.05	<0.03	<0.1
Limits	1.0	5.0	10	-	5.0	-	2	10

Breaking Strength of Tiles

The breaking strength of tile specimens was determined according to BS EN 13748-2:2004 requirements. The standards state that the minimum 28-day breaking strength is 2.8 MPa for tiles intended for external use. Figure (4) shows the average breaking strength of tiles *versus* age for all percent sludge-cement replacements. The breaking strength reported in the Figure is the average value of four tile specimens. The Figure indicates that the breaking strength of all tiles produced develop with age. The 28-day strength for tiles made with 10%, 20%, 30%, 40% and 50% sludge-cement replacements was 98.5%, 92.7%, 86.8%, 85.3% and 72.1%, respectively, of the strength of reference tiles. However, with the exception of 50% sludge-cement replacement, all of the tiles produced comply with the minimum breaking strength of 2.8 MPa required by the standards. This is illustrated in Figure

(5), which shows a comparison between breaking strength requirement and 28-day average breaking strength of tiles for all percent sludge-cement replacements.

Figure (6) presents the average 28-day breaking strength of tiles *versus* percent sludge-cement replacements. The Figure indicates the presence of an inversely proportional linear relationship between sludge-cement percent replacement and breaking strength. The data presented in Figure (6) are regressed using a line and yielded the equation:

$$\text{Breaking Strength (MPa)} = -0.018 \times (\text{\% Replacement}) + 3.48$$

The above equation has a coefficient of determination (R^2) of 0.925 and a coefficient of correlation (r) of -0.956, indicating that when one variable increases the other tends to decrease (Montgomery and Runger, 1999). The above equation indicates a decrease in the breaking strength of tiles produced as the amount of sludge-cement replacement increases, and can be employed to further predict breaking strengths of tiles produced with sludge-cement replacement percentages not investigated in this study.

Toxic Characteristic Leaching Procedure (TCLP)

The Toxicity Characteristic Leaching Procedure (TCLP) was developed by the USEPA (1992) to simulate the leaching of metals and organic compounds from solids under severe temperature and pressure conditions normally encountered in landfills. The TCLP was carried out in this investigation to assess the leachability of possible heavy metals from tiles made with sludge replacement.

Table (3) shows metal concentrations in the raw sludge and TCLP regulatory limits along with results of heavy metal concentrations in mg/L of the TCLP for tiles with the different sludge-cement replacements used in the study. Investigation of the Table indicates that very low concentrations of metals are detected when compared to the regulatory limits of these metals. This can be explained by the chemical composition of raw sludge presented in the first row of Table (3), where measured metals were all acceptable. This is in agreement with the finding of the Florida Department of Environmental Protection which stated that, in general, water treatment sludge do not contain pollutants that would pose threat to humans or to the environment (Florida Department of Environmental Protection, 2006).

CONCLUSIONS

This study investigated the use of water treatment sludge for cement replacement in the production of paving tiles for external use. The study concluded that all tiles produced are non-vitreous, with a water absorption that is around 10%. The breaking strength results showed development with age, and that, with the exception of 50% sludge-cement replacement. All of the tiles produced comply with the minimum breaking strength of 2.8 MPa required by the standards. Additionally, the study concluded that a decrease in the breaking strength of tiles is accompanied with an increase in the amount of sludge-cement replacement, and presented a linear relationship to predict breaking strengths of tiles produced with sludge-cement replacement percentages not investigated in this study. The study showed that very low concentrations of metals are detected in the TCLP leachate of tiles. This investigation ultimately concluded that sludge-cement replacement can potentially be used to yield paving tiles that comply with the standards for tiles intended for external use. This will eventually lead to a significant reduction in the cost of tiles and provide a safe and environmentally sound option for the disposal of water treatment sludge.

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REFERENCES

Ahmadi, B. and Al-Khaja, W. 2001. Utilization of Paper Waste Sludge in the Building Construction Industry. *Resources, Conservation and Recycling*, 32: 105-113.

American Public Health Association (APHA). 1999. Standard Methods for the Examination of Water and Wastewater. 19th ed., Washington DC: APHA.

ASTM C33/C33M-08. 2008. Standard Specification for Concrete Aggregates. *Annual Book of ASTM Standards*, vol. 4.02.

ASTM C136-06. 2008. Standard Test Method for Sieve Analysis of Fine and Course Aggregates. *Annual Book of ASTM Standards*, vol. 4.02.

ASTM C150-07. 2008. Standard Specification for Portland Cement. *Annual Book of ASTM Standards*, vol. 4.01.

Babatunde, A. and Zhao, Y. 2007. Constructive Approaches Toward Water Treatment Works Sludge Management: an International Review of Beneficial Reuses. *Critical Reviews in Environmental Science and Technology*, 37 (2): 129-164.

Baker, R., White, D. and van Leeuwen, J. 2004. Reuse of Lime Sludge from Water Softening and Coal Combustion Byproducts. Iowa Department of Transportation, Final Report, Number TR-459.

BS EN 13748-2. 2004. Terrazzo Tiles, Terrazzo Tiles for External Use. BSI-British Standards Institution, London.

Cheilas, A., Katsioti, M., Georgiades, A., Malliou, O., Teas, C. and Haniotakis, E. 2007. Impact of Hardening Conditions onto Stabilized/Solidified Products of Cement–Sewage Sludge–Jarosite/Alunite. *Cement and Concrete Composites*, 29: 263-269.

Chugh, Y., Patwardhan, A., Munish, S. and Botha, F. 2006. Development of Construction Materials Using Sulfite-Rich Scrubber Sludge and Fly Ash. *Fuel*, 85: 2323-2329.

Derucher, K., Korfiatis, G. and Ezeldin, S. 1998. Materials for Civil and Highway Engineers, 4th ed. Prentice Hall.

Ferreira, C., Ribeiro, A. and Ottosen, L. 2003. Possible Applications for Municipal Solid Waste Fly Ash. *Journal of Hazardous Materials*, B96: 201-216.

Florida Department of Environmental Protection. 2006. Guidance for Land Application of Drinking Water Treatment Plant Sludge. Florida Department of Environmental Protection: Solid Waste Section and Drinking Water Program, Tallahassee, Florida.

Hytiris, N., Kapellakis, I., La Roij de, R. and Tsagarakis, K. 2004. The Potential Use of Olive Mill Sludge in Solidification Process. *Resources, Conservation and Recycling*, 40: 129-139.

Jordan Institution for Standards and Metrology (JISM). 2007. Terrazzo Tiles-Part 2: Terrazzo Tiles for External Use. Number: JS 45-2:2007 EN 13748-2:2004, 2nd edition.

Lim, S., Jeon, W., Lee, J., Lee, K. and Kim, N. 2002. Engineering Properties of Water/Wastewater-Treatment Sludge Modified by Hydrated Lime, Fly Ash and Loess. *Water Research*, 36: 4177-4184.

Malliou, O., Katsioti, M., Georgiadis, A. and Katsiri, A. 2007. Properties of Stabilized/Solidified Admixtures of Cement and Sewage Sludge. *Cement and Concrete Composites*, 29: 55-61.

Ministry of Water and Irrigation (MWI). 2007. Open Files. Amman, Jordan.

Mishulovich, A. and Evanko, J. 2003. Ceramic Tiles from High-Carbon Fly Ash. International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, Paper No. 18.

Monteiro, S., Vieira, C., Ribeiro, M. and Silva, F. 2006. Red Ceramic Industrial Products Incorporated with Oily Wastes. *Construction and Building Materials*, 21: 2007-2011.

Montgomery, D.C. and Runger, G.C. 1999. Applied Statistics and Probability for Engineers, 2nd ed. New York: John Wiley and Sons.

Qasim, S., Motley, E. and Zhu, G. 2000. Water Works Engineering, Prentice Hall, India.

Technology Assistance Partnership. 1999. Testing of Recycled Glass and Inorganic Binder Paving Tiles. FINAL REPORT, Prepared for CWC: A Division of the Pacific North-West Economic Region (PNWER), 2200 Alaskan Way, Suite 460, Seattle, WA 98121.

Townsend, T., Jang, Y., Jain, P. and Tolaymat, T. 2001.

Characterization of Drinking Water Sludge for Beneficial Reuse and Disposal. Report Published by State University System of Florida and Florida Center for Solid and Hazardous Waste. Sponsored by the Florida Center for Solid and Hazardous Waste Management and the Florida Department of Environmental Protection.

USEPA. 2001. Test Methods for Soil and Waste pH, METHOD SW-846 9045C. EPA Publication, United States Environmental Protection Agency.

USEPA. 1992. The Toxicity Characteristics Leaching Procedure, US Code of Federal Regulations, 40th ed., Part 261, Appendix II.