Corrosivity and leaching behavior of controlled low-strength material (CLSM) made using bottom ash and quarry dust

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Disposal of industrial waste incineration bottom ash and quarry dust causes environmental problems. Disposal of these wastes into landfill needs to be reduced or rather discontinued for sustainable development. Hence there is a necessity to find ways of reusing these materials in bulk quantities. Oneway is to use the bottom ash and quarry dust in CLSM applications. CLSM refers to cementitious slurry consisting of a mixture of fine aggregate or filler and water, which is used as a backfill and structural fill. This mixture is capable of filling all voids in irregular excavations and hard to reach places (such as under and around pipes), is self-leveling, and hardens in a matter of a few hours without the need for compaction in layers. The compressive strength of flowable fill mixtures should be less than 8.3 MPa. It is possible to use these materials in CLSM (Sivakumar et al., 2012). The corrosivity and leachate analysis were done by the authors on bleed, and, leachate collected by soaking the hardened CLSM up to 28th day (Sivakumar et al., 2012, 2009a,b). However rigorous testing on CLSM for corrosivity and leaching behavior such as long term leaching and toxicity characteristic leaching procedure (TCLP) have not been carried out.

Corrosivity is a means to identify materials that are harmful to human health or the environment due to their ability to mobilize toxic metals if discharged into the environment, to corrode handling, storage, transportation, and management equipment, or to destroy human or animal tissue in the event of inadvertent contact. Corrosion can occur when water or leachate reacts with metal parts. A solid waste exhibits corrosivity if a representative sample of the waste has the property that is aqueous and has a pH less than or equal to 2, or, greater than or equal to 12.5 (Sivakumar et al., 2009a). Corrosivity of CLSM mixtures is assessed in terms of pH and electrical resistivity.

The environmental compatibility of building materials is determined by carrying out leaching tests for contaminants like heavy metals and salts which have an impact on the environment. Leaching makes it possible to define the life cycle of materials within a given time period by determining the release of contaminants in a particular setting such as rain and moisture content. Normally the materials are assessed in a solid monolithic state according to their porosity, which in turn depends on the water/

cement ratio, the cement type, admixture, compaction and curing (Valla and Vazquez, 2002). The diffusivity of the contaminants can be calculated using two models. First model was based on the Fick's hypothesis which assumes a constant diffusion as given (Poon et al., 2001) in the following form:

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where D_e is the effective diffusivity (cm2/s), V the volume of specimen (cm3), S the surface area of the specimen (cm2), t_n the duration of nth leaching interval (s) and a_n, A_o are the concentrations of contaminants at nth leaching time at the beginning. The values of slope of the linear regression of the data in the plot between cumulative concentration and $t_{1/2}$ will be directly proportional to the diffusion coefficient. The diffusion coefficient was calculated from the slope of the plot using the above equation and expressed as diffusion coefficient pD_e (pD_e ¼ _$logD_e$). This can be used to compare the relative mobility of contaminants on a uniform scale, which varies from 5 (D_e ¼ 10_5 cm2/s very mobile) to 15 (D_e ¼ 10_15 cm2/s immobile) (Moon and Dermatas, 2006). The second type of diffusion was based on the ANS 16.1 (Cote and Hamilton, 2005) model which evaluates the long term leachability of contaminants by calculating the effective diffusivity of the leached samples D_e using the following model:

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This was then used to find the leachability index (LX) for each contaminant. The LX values were derived from effective diffusivity values obtained on each leaching period. The average value of effective diffusivity for each leaching period was taken as the LX. This was then expressed as negative of log(D_e). The LX can be used as a performance criterion for the utilization and disposal of solidified waste. A waste contaminant with LX less than 6.5 is considered to be very mobile, from 6.5 to 8 is moderate; more than 8 is considered of very low mobility (Singh and Pant, 2006).

The objective of this paper is to study the corrosivity and leaching behavior of CLSM mixtures made using industrial waste incineration bottom ash and quarry dust. Various mix proportions of CLSM were made with industrial waste incineration bottom ash, quarry dust, cement and water. Tests were conducted on the fresh state and hardened state up to 126 days in order to fulfill the

objective. The significance of this work was the study of leaching of contaminants from the CLSM mixtures. This paper is culminating from a continuing research on this topic by the authors.

Materials and methods

Materials used

Ordinary Portland cement conforming to Malaysian Standard MS 522 Part 1 2003 was used. The bottom ash, which was obtained from the industrial waste incineration plant operated by Kualiti Alam Sdn Bhd, Malaysia, contains particles of various sizes from fine powder to 60 mm. It was first dried in an oven at 105 _C until constant mass and then sieved using a 10 mm sieve. Particles that are less than 10mmsize were used in the investigation. The bottom ash had un-compacted bulk density of 478 kg/m3, and a specific gravity of 1.83. Quarry dust was obtained from Hanson Quarry Products (M) Sdn Bhd quarry plant located at Batu 11, Cheras, Kuala Lumpur, Malaysia and prepared in the same manner like the bottom ash for use in this investigation. The specific gravity of quarry dust was 2.59; its un-compacted bulk density was 1440 kg/m3. Table 1 shows the chemical properties of constituent materials. The concentration of various contaminants in materials based on the toxicity characteristic leaching procedure (TCLP) is shown in Table 2. Tap water filtered through a water filter was used in the investigation. It is mentioned that the assessment of the mineralogy of bottom ash is necessary because it will assist us know under which form heavy metals are present in the waste. An X-Ray diffraction test is recommended for this purpose.

Sample preparation

The mix proportions used in the investigation are shown in Table 3. The formulations were calculated by mass and volume on solid materials at oven-dry condition using a back calculation procedure based on measurements made on the fresh mixture for density, density values of raw materials, and water content. The bottom ash, quarry dust, and cement were first placed in a tilting type mixer, and dry mixed for 1 min. Sufficient quantity of water was then added and the contents mixed for 2 min. The sample was then tested for flow consistency according to ASTM D 6103-02. CLSM is considered flowable if the spread diameter is at least 200 mm (Sivakumar et al., 2009b). Hence the spread diameter for all the mixtures was kept constant at 200 _ 10 mm. Water content was then adjusted until the flow was 200 _ 10 mm. The contents were then mixed for another 2 min. The mixture thus obtained,was filled in 70.7 mm3 moulds made of Perspex sheet for leach testing. The moulds were washed thoroughly with 5 vol% nitric acid solution prepared using nitric acid purchased from Merck Malaysia

before use to eliminate chemical contamination. Two cube moulds of size 100 mm were used for measurement of electrical resistivity of hardened CLSM mixtures. The inside surface of the moulds were covered with cling film before pouring fresh mixture to avoid the CLSM mixture from contacting the mould. Four stainless steel electrodes of 100 mm long and 5 mm diameter were kept suspended in the moulds at distances of 30 mm centers by means of a holding clamp. The electrodes were suspended for a depth of 60 mm from the top surface of the mould. The electrical resistivity moulds were filled with fresh CLSM mixture in three layers, each layer was subjected to low amplitude vibration for 5 s. All the moulds were kept covered with wet burlap in the laboratory environment for one day, and then transferred to the curing environment which is maintained at 22 _C and 95% relative humidity. The samples were removed from the moulds after 28 days of curing.

Analytical procedure

Tests for corrosivity in terms of pH and electrical resistivity, and measurement of concentration of various contaminants were carried out in the present investigation. The pH of CLSM mixtures was measured on the bleed and also on the leachate obtained by conducting the crushed and whole block leaching tests using a digital PH meter. The electrical resistivity was measured on the hardened CLSM mixtures at 28 days by using Nilsson's soil resistance meter. Duplicate samples were used for electrical resistivity test and triplicate samples for pH measurement. The coefficient of variation of the test results on each day of tests was kept below 15 by substituting additional samples when necessary

Whole block leaching and crushed block leaching tests were performed to simulate short and long term leaching behavior of CLSM samples. The whole block leaching simulates immediate leaching behavior once the CLSM is placed in position and hardened whereas the crushed block leaching simulates long or extended leaching after sample break down. In whole block leaching, the leaching medium is replaced periodically after intervals of static leaching. The tests were carried out in a closed 2500 ml acid rinsed polytetrafluoroethylene (PTFE) beakers using the deionized water as leaching medium. The deionized water for this investigation was obtained from the Hamilton distiller unit available in the laboratory which processed the filtered tap water supplied by Syabas, Malaysia into deionized water. The deionized water was intended to simulate neutral precipitation that might be in contact with the CLSM during its service life. Cube specimens of size 70.7 mm hardened for 28 days were kept in 2500 ml PTFE beakers. The specimenwas kept immersed in the leaching medium with a liquid over solid ratio of 5. All the surface of the specimen was exposed to the leachant. The beaker was sealed and kept in an

air conditioned room for the entire duration of the measurement.

Three samples were tested separately and the average values taken for leachability analysis with the coefficient of variation less than 15. The leachant renewalwas done at 1, 3, 7,14, 28, 63, and 126 days. It was assumed that the leaching rate would decrease with time and therefore the contact time between leachant renewals increased to ensure that the leached contaminants can be analytically measured. The test beakers were kept static and not agitated. This was because the dispersion rate of the contaminants in the leaching medium was assumed to be much larger than their leaching rate, thus eliminating concentration gradient in the leachant (Poon et al., 2001). The leachate obtained for each leaching period was filtered through a 45 micron membrane filter by vacuum filtration and then tested for pH using Hanna Instrument's microprocessor pH meter model No. 211. The sample was acidified using nitric acid to a pH of below 2, and then transferred into highdensity polyethylene (HDPE) sample bottles and stored in a refrigerator for heavy metals testing. Analysis of leachates for all the contaminants was done using a Perkin Elmer Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) except Mercury for which an Atomic Absorption Spectrometer was used.

for which an Atomic Absorption Spectrometer was used. Crushed block leaching tests were performed according to TCLP US EPA Method 1311 on hardened mixtures at 28 days. Flowable fill cubes 70.7 mm size cured for 28 days were crushed and sieved through a 9.5mmsieve. The contents that passed through the sieve were taken as samples for getting the leachate. Forty grams of the sample and 800 ml of extraction fluid No. 2 (acetic acid solution with pH < 2) were transferred into a HDPE bottle. The bottle were then closed tightly and kept in the TCLP extractor which was made to rotate at 30 rpm for 18 h. The leachant was then taken out from the extractor, pH was measured, filtered using a 45 micron membrane filter and stored in the same manner as the whole block leaching samples. TCLP tests were also done on the crushed flowable fill samples using deionized water as leachant in the same manner as for extraction fluid No. 2. This was to compare the effect of acid medium on the Leachability. Triplicate samples were tested and the average values reported with coefficient of variation less than 15.

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