CONTROLLED LOW-STRENGTH MATERIAL USING INDUSTRIAL WASTE INCINERATION BOTTOM ASH AND REFINED KAOLIN

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The scheduled industrial waste generation in Malaysia in the year 2007 was 11,38,839 metric tons [1]. This waste had to be properly managed and disposed of without causing any harmful environmental effects. Hence, civil engineers were left with the challenge of managing the industrial waste. Research was conducted to develop technologies for the efficient management, treatment, reuse, and disposal of these wastes.

Kualiti Alam Sdn Bhd, Malaysia is authorized to transport, collect, treat, and dispose of the industrial wastes produced in the country. They treat around 120 000 metric tons of industrial wastes annually. Incineration of these industrial wastes produces large quantities of bottom ash, which are sent to secured landfills. However, disposal by land filling is not a sustainable solution. Hence, various methods of using the bottom ash need to be developed. Incineration of bottom ash, if reused, will ensure sustainability, reduce pollution and environmental degradation, generate revenue, and preserve natural virgin resources. One of the ways of using the incinerated bottom ash is to use it as controlled low-strength material (CLSM).

CLSM, in its simplest form, is slurry made by mixing sand, cement, ash, and water. It is self compacting, flowable, and used primarily as a replacement for soil and structural fillings. ACI committee 229 [2] defines CLSM as a material having a compressive strength of 8.3 MPa or less. CLSM offers many advantages compared to conventional soil fills. Some advantages of CLSM over conventional back fills are easy placement with no vibration, less onsite labor requirements, ease of placement in intricate locations, no settlement problems, strength, durability, and flexibility to incorporate locally available nontraditional materials.

Many waste materials were successfully used to develop CLSM. To name a few, there are flue gas desulfurization material, foundry sand, wood fly ash, dry scrubber ash, and glass cullets [3]. However, the reuse of industrial waste incineration bottom ash has not been fully explored yet. This is because of the problem of leaching of hazardous materials from the bottom ash and, consequently, refraining the researchers from thinking about the potentials of reusing the bottom ash.

This paper presents the experimental investigation carried out on CLSM mixtures made using industrial waste incineration bottom ash and refined kaolin. CLSM mixes were made with the bottom ash, refined kaolin, cement, and water. Various tests were conducted on the CLSM mixes in fresh and hardened states and the results were discussed.

Kaolin is one of the most widely used industrial minerals. Total world output exceeds 250 million tons [4]. Kaolin clay is chemically hydrated aluminium silicate and structurally unmodified. Refined kaolin is made by slurrying the raw clay and then centrifuging or hydro-cycloning it to remove impurities. Chemical bleaching is done

to improve the brightness of the kaolin before it is produced in specific grades. Kaolin has a platy structure and is hydrophilic and, thus, readily water dispersible.

EXPERIMENTAL METHODS

Materials Used

Ordinary Portland cement conforming to BS EN 197 – 1 : 2000 was used in this investigation. Bottom ash was obtained from the industrial waste incineration plant operated by Kualiti Alam Sdn Bhd, Malaysia. The slag contains particles of various sizes from fine powder to 60 mm size. It comes in a wet state, and the finer particles make the slag sticky and difficult to work with. Hence, the slag was first dried in an oven at 105^0 C until constant mass, and then sieved through a 10 mm sieve to eliminate unwanted substances and particles larger than 10 mm size. The chemical composition of cement, bottom ash, and refined kaolin are shown in Table 1. The grading curve for bottom ash is shown in Figure 1. The bottom ash has a fineness modulus of 3.06, specific gravity of 1.84, uncompacted bulk density of 911 kg/m^3, and compacted bulk density of 964 kg/m^3. The percentage of particles of bottom ash finer than 75μm was 12 percent. As per BS 882 [5], the grading of slag falls in the range of coarse and medium fine aggregate. Commercially available refined kaolin was used in this investigation. The various physical properties of kaolin are listed in Table 2. It has an average particle size from 3 to 5.5 microns, and a specific gravity of 2.6. Potable tap water was used in the investigation.

Mix Proportions and Sample Preparation

The mix formulations used in the investigation are shown in Table 3. The bottom ash, refined kaolin, and cement were first placed in a tilting type mixer, and dry mixed for one minute. A sufficient quantity of water was then added and the contents mixed for two minutes. The sample was then tested for flow consistency as per ASTM D 6103 [6]. This was done by placing an open ended cylinder 76 mm internal diameter and 150 mm long on a flat surface, pouring CLSM into it up to the top surface, and lifting the cylinder up vertically. The spread diameter of CLSM was then measured. As per ACI 229 [2], the CLSM is considered flowable if the spread diameter is at least 200 mm. Water content was then adjusted until the flow was 200+ 20 mm. The contents were then mixed for another 2 minutes. CLSM was then filled in 70.7 mm size 5 gang cube moulds, a 150 mm cube mould for ISAT, a CBR mould, and about 800 ml in a 1000 ml plastic measuring jar for bleed water measurement, and 100 X 200 mm cylinder moulds for settlement. All moulds were kept covered with wet burlap in the laboratory environment for one day, and then shifted to the curing environment of 95 percent relative humidity and 22^0 C. The cubes were removed from the moulds on the day of testing.

Tests

Tests for compressive strength, stiffening time, density, bleeding, ISAT, CBR, settlement, water absorption, sorption, corrosivity, and leaching of heavy metals and salts were carried on the CLSM mixtures in this Investigation

The compressive strength of CLSM was measured on 70.7 mm cubes at 7, 14, and 28 days. A universal testing machine of 100 kN capacity was used for the testing. The loading rate was kept at 0.6 mm/minute. It took 4 to 8 minutes for failure of each specimen. Five cubes were tested on each day and average values reported. The coefficient of variation of the test results on each day of tests was kept below 15.

A stiffening time test was done according to ASTM C 403 [7] on mortar sieved from the fresh CLSM mixture through a 5 mm sieve. Around 3.5 liters of mortar were filled in three layers into two five-liter metal containers. The containers were then kept on a low amplitude vibrating table for 5 seconds to eliminate air pockets. The containers were then closed with a lid, and kept covered with wet burlap in the air conditioned room at 21^0 C at a relative humidity of around 60 percent for the entire duration of testing. The penetration resistance was measured using 323 mm^2, 161 mm^2, 65 mm^2, 32 mm^2, and 16 mm^2 steel penetration needles depending on the resistance development. The penetration load was measured by a deflectometer with an accuracy of 0.002 mm, which is attached to a calibrated proving ring attached to the penetrometer needles. Bleed water accumulated at the top surface of the mortar was removed before each penetration reading. The first reading was taken at two hours from the addition of water to CLSM mixtures. Subsequent readings were taken at 30 minute intervals until the required penetration resistance was reached. Duplicate readings were taken for each observation.

The density of fresh CLSM was measured by filling a 1.5 liter copper container with CLSM and measuring the weight using a scale accurate to 5 grams. The copper container was pre-calibrated for its volume. The average of two observations was taken for the fresh density. The hardened density of CLSM was measured by measuring the weight of each 70.7 mm cube before testing for compressive strength. An average of 5 values was reported as the hardened density.

The test for bleeding of CLSM was done by filling about 800 mL of fresh CLSM in a 1000 mL measuring jar. The jar was closed and kept in an air conditioned room at 21^0C. After the CLSM was stabilized, the volume of CLSM, and the bleed that was accumulated over the solid particles of CLSM, were then recorded. The bleed is then expressed as a percentage of the initial volume of CLSM.

An initial surface absorption test was done on 150 mm cubes at 28 days according to the British standard 1881 part 208 [8]. The cubes were kept in an oven on the 21^{st} day at 90^0C, removed from the oven on 27^{th} day, and kept in a desiccator for cooling to room temperature. The cubes were taken out of the desiccator on the 28^{th} day for testing.

A CBR test was done on the hardened CLSM kept in the CBR mould and cured for 28 days. The test was done according to the British standard BS 1377 part 4 [9]. The settlement of the hardened CLSM was measured by measuring the height of 100 X 200 mm cylinders after 28 days of curing. The settlement is expressed as a percentage of the original height.

The test for water absorption was done on three 70.7 mm cubes at 28 days according to BS 1881-part 122 [10]. The cubes were kept in an oven at 105^0C on the 21^{st} day. The cubes were taken out of the oven on the 27^{th} day and kept in a dessicator for cooling to room temperature. The cubes were tested on the 28^{th} day. The cubes were

immersed in water with the longitudinal axis horizontal, and a head of water of 25+5 mm was maintained over the cubes for 30 minutes. The change of weight of cube is used in calculating the water absorption. A correction factor is also applied on the water absorption values as envisaged in the BS 1881.

The sorptivity test measures the rate of absorption of water by capillary suction of unsaturated concrete placed in contact with water with no head of water [11]. The sorptivity of CLSM samples were measured by keeping the 70.7 mm cube on two 6 mm rod supports in a tray, and maintaining the bottom 2 to 5 mm height of the cube in contact with water. The increase in mass of cubes was recorded every 30 minutes up to 4 hours from the start of the test. The mass increase is then plotted against the square root of time. The slope of the straight line fit of this plot was the sorptivity. Three cubes were tested for sorptivity at 28 days and the average value reported.

Corrosivity is a means to identify materials that are potentially a hazard 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 water 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 [12]. However, this range is not applicable to the corrosion or passivity of all materials. For example, higher pH values provide passivity to exposed steel but may corrode glassy material. The corrosivity of CLSM was measured as pH of bleed and leachate collected from the CLSM. Bleed water collected from the bleed test was used. The leachate was obtained by immersing one 70.7 mm cube in two liters of deionized water on day 7 in a plastic container. The container was kept closed in the air conditioned room at 21^0C. The cube was removed from the container on the 28^{th} day, and the water in the container was used as leachate. The bleed and leachate were also analyzed for the concentration of heavy metals and salts. The Toxicity Characteristic Leaching Procedure as per Environmental Protection Agency (EPA) (USA), Test number SW-846 2000, 40 CFR Part 261 1986 was used for this analysis. An inductively coupled plasma optical emission spectrometer was used for these tests.