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

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الخلاصة:

تشرح هذه الورقة تفاصيل التحقيقات التي نُفذت لدراسة أداء رماد القاع للمخلفات الصناعية المحترفة، والكاولين المصفى لإنتاج مادة منخفضة القوة (CLSM). وقد تم تصميم مزيج الـ CLSM بكميات مختلفة من رماد القاع المحروق ، والكاولين المصفى والأسمنت. وأيضا تم ضبط محتوى الماء للحصول على انسيابية كافية. ومن ثم تم تنفيذ اختبارات على خلطات CLSM لاختبار الكثافة، وزمن التصلب، والنزيف، والهبوط ، وامتصاص الماء، ومحتوى الرطوبة ، ونسبة تحمل كاليفورنيا (CBR) ، وامتصاص السطح الأولي و وقوة الضغط.

وقد تمت أيضا دراسة التآكل والترشيح للمعادن الثقيلة والأملاح على النزيف والارتشاح.

وتراوحت اختبارات الضغط على CLSM من 0.36 to 4.4 MPa وقيم CBR وتراوحت من 10 to 46 وقيم ISAT عند ساعة واحدة من 0.56 to 4.76 مم / م2 / ثانية.

إن اختبار أي من المعادن الثقيلة لم يتجاوز الحدود القصوى في الارتشاح.

وتبين أيضا أن إضافة الكاولين قد تتحكم في تطور قوة الضغط ، وتُقلل من الامتصاص السطحي الأولي، CBR ، وقيم امتصاص الماء. وقد ظهر أن رماد القاع ، جنبا إلى جنب مع الكاولين المصفى يمكن أن يستخدم بنجاح في CLSM مما يسهم في تحقيق الاستمرارية في الهندسة المدنية.

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Paper Received May 5, 2009; Paper Revised May 30, 2009; Paper Accepted June 8, 2009

ABSTRACT

This paper reports the details of investigations carried out to study the performance of industrial waste incineration bottom ash and refined kaolin to produce controlled low-strength material (CLSM). CLSM mixes were designed with varying amounts of incineration bottom ash, refined kaolin, and cement. Water content was adjusted to get sufficient flowability. Tests for density, stiffening time, bleed, settlement, sorptivity, water absorption, moisture content, California bearing ratio, initial surface absorption, and compressive strength were carried out on the CLSM mixtures. Study for corrosivity and leaching of heavy metals and salts on the bleed and leachate were also performed. The compressive strength of CLSM tested ranged from 0.36 to 4.40 MPa. CBR values ranged from 10 to 46 and ISAT values at 1 hour from 0.56 to 4.76 ml/m^2/s. None of the heavy metals tested exceeded the threshold limits in leachate. Addition of kaolin controls the compressive strength development, and reduces initial surface absorption, California bearing ratio, and water absorption values. It is shown that the incineration bottom ash, along with refined kaolin, can be successfully employed in CLSM, thereby contributing to sustainability in civil engineering practice.

Key words: Controlled low-strength material, California bearing ratio, initial surface absorption, stiffening time, sorptivity, water absorption, compressive strength, corrosivity, and leachate

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1. INTRODUCTION

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.

2. EXPERIMENTAL METHODS

2.1. 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.

Table 1. Chemical Composition of Cement and Bottom Ash

Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	P_2O_5	MnO	LOI
Cement	65.20	21.27	6.19	3.64	0.88	0.71	0.19	0.22	0.09	0.08	1.53
Bottom ash	4.14	43.85	8.37	11.91	0.79	0.71	2.73	2.71	1.73	0.12	22.10
Refined kaolin	0.01	52.85	32.50	0.85	0.10	2.83	<0.01	0.38	0.08	0.01	10.40

Table 2. Physical Properties of Refined Kaolin

PROPERTY	VALUE
Specific Gravity	2.6
Average particle size	3.0 – 5.5 µm
Particles < 2 µm	35%
325 mesh residue	Below 0.2%
Blaine fineness (m^2/kg)	873
Brightness(GE)	75 – 82%
pH (30% solution)	3.5 – 6.0

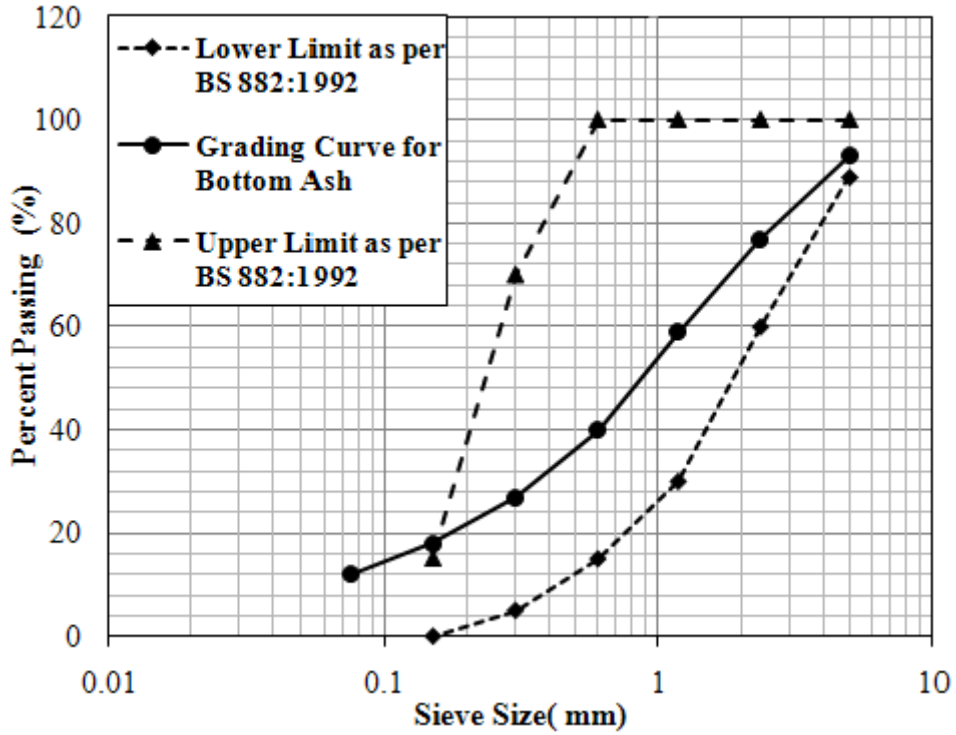

Figure 1: Grading curve for bottom ash

2.1. 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$\pm$ 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.

Table 3. Mix Proportions

MIX ID	BULK PROPORTION (kg/m^3)				PROPORTION BY WEIGHT				w/	(c+k)/BA	k/c
	BA	Cement	Kaolin	Water	Cement	BA	Kaolin	Water	(c+k)		
A	1026	103	103	432	1	10	1.0	4.2	2.1	0.2	1.00
B	763	114	114	458	1	6.7	1.0	4.0	2.0	0.3	1.00
C	868	174	64	422	1	5.0	0.4	2.4	1.8	0.3	0.37
D	720	180	180	510	1	4.0	1.0	2.8	1.4	0.5	1.00
E	767	230	230	461	1	3.3	1.0	2.0	1.0	0.6	1.00
F	839	227	113	454	1	3.7	0.5	2.0	1.3	0.4	0.50
G	687	275	137	490	1	2.5	0.5	1.8	1.2	0.6	0.50
H	797	256	128	459	1	3.1	0.5	1.8	1.2	0.5	0.50
I	708	213	159	508	1	3.3	0.7	2.4	1.4	0.5	0.75

2.2. 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 21st day at 90^0C, removed from the oven on 27th day, and kept in a desiccator for cooling to room temperature. The cubes were taken out of the desiccator on the 28th 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 21st day. The cubes were taken out of the oven on the 27th day and kept in a dessicator for cooling to room temperature. The cubes were tested on the 28th day. The cubes were immersed in water with the longitudinal axis horizontal, and a head of water of 25$\pm$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.

3. RESULTS AND DISCUSSION

3.1. Fresh Properties

3.1.1. Stiffening time and penetration resistance

The stiffening time of CLSM mixes for penetration resistance values of 344 kPa, 689 kPa, 1379 kPa, and 2758 kPa are given in Table 4. The time from the addition of water to the time the penetration resistance reaches 344 kPa is defined as the initial set penetration resistance [12]. The initial set for the penetration resistance of 344 kPa is in the range of 6.5 hours to 9.25 hours. The time to reach the penetration resistance of 2758 kPa, which is the threshold for vehicle loads, [12] is from 10.5 hours to 22.25 hours. This means additional layers of CLSM can be allowed on the CLSM mixtures after 6.5 to 9.25 hours and the CLSM is ready for the vehicle loads after 10.5 to 22.25 hours. The relationship between initial setting time and powder to BA ratio (powder/BA) which reflects cement to bottom ash ratio (c/BA), and cement and kaolin to bottom ash ratio (c+k)/BA is shown in Figure 2. It can be seen in Figure 2 that the slope of the linear trend line for c/BA is more than the slope of the linear trend line for (c+k)/BA. This means that kaolin controls the variation range of initial setting time values. The relationship between initial setting time and water to powder ratio (w/c, and w/(c+k)) is shown in Figure 3.

The slope of the trend line of w/(c+k) in Figure 3 is more than the slope of the trend line of w/c. This is because the addition of kaolin increases the powder content and reduces the water/powder ratio and, hence, increases the slope. Addition of more water increases the setting time of CLSM mixtures.

Table 4. Stiffening Time, Bleed, and pH

MIX ID	STIFFENING TIME (HOURS) @				BLEEDING (%)
	344 kPa	689 kPa	1379 kPa	2758 kPa	
A	8.25	10.25	14.00	22.25	1.0
B	9.25	12.75	19.35	na	0.4
C	na	na	na	na	1.0
D	8.25	9.50	11.75	16.50	0.6
E	6.50	8.00	9.40	11.25	1.0
F	7.00	8.00	9.25	11.00	0.2
G	7.00	8.00	9.00	10.50	0.4
H	8.00	8.75	10.25	12.50	0.1
I	7.25	8.50	11.00	15.50	0.0

Na= Data not determined

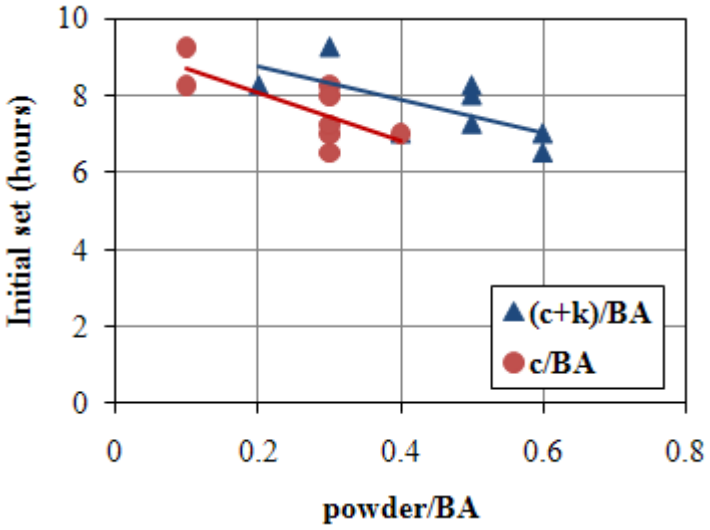

Figure 2: Relationship between initial setting time and (powder/BA)

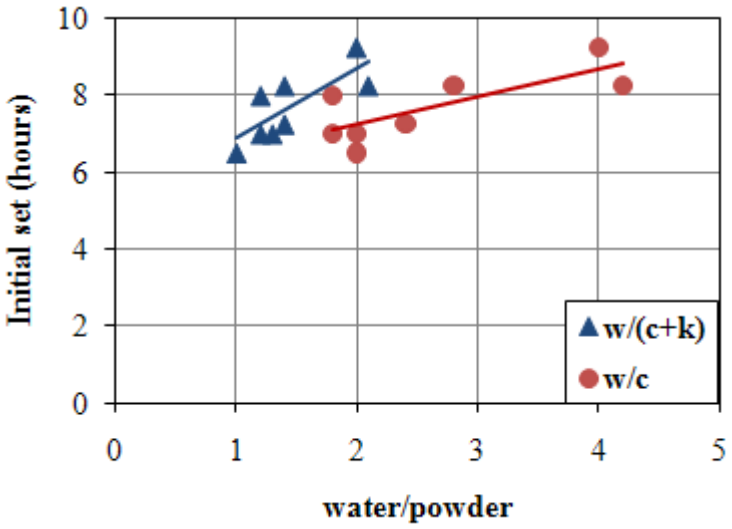

Figure 3: Relationship between initial setting time and water/powder ratio

3.1.2. Bleeding

The excess water added to maintain the required flowability of CLSM comes out as bleed. The bleed expressed as a percentage of the original volume of CLSM is shown in Table 4. The bleed varies from zero percent to one percent. Bleeding is a measure of the stability of CLSM, which is defined as the potential of the particles to remain in suspension. CLSM is considered stable if the sedimentation of solids is less than 5 percent at 2 hours [13]. However, the bleed recorded in the present study is after bleeding was stabilized and, hence, represents the maximum bleed values. Hence, all the CLSM mixtures used in the investigation are stable. Bleed increases with increase in w/c, as evident in Figure 4. It can be seen from Table 4 that CLSM mixtures with (c+k)/BA between 0.4 and 0.5 produced minimum bleeding.

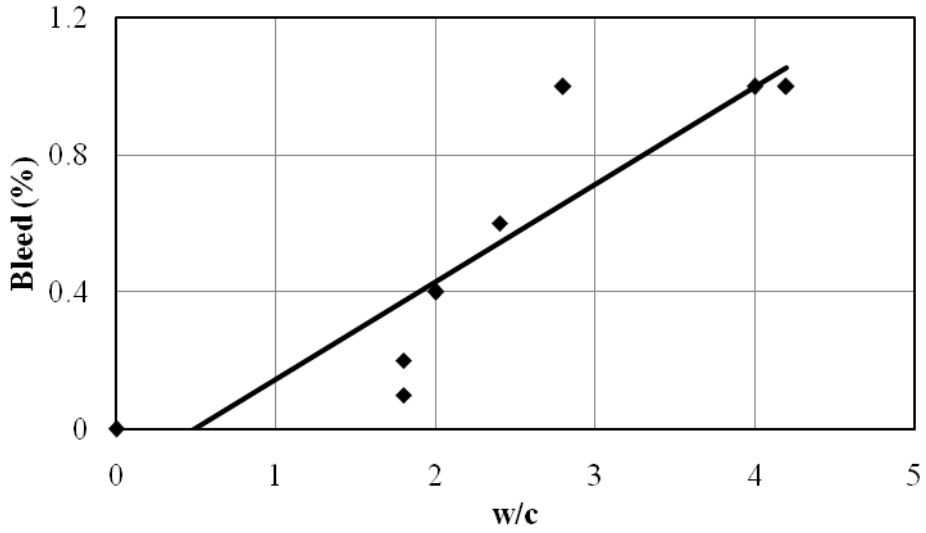

Figure 4: Relationship between bleed and w/c

3.2. Hardened Properties

3.2.1. Density

The density values for the CLSM mixes are given in Table 5. Hardened density is less than fresh density. The hardened density at 28 days of the CLSM mixes varies from 1435 kg/m^3 to 1566 kg/m^3. This is comparable to that of sand and sandy loam soils whose bulk density values range from 1200 kg/m^3 to 1800 kg/m^3[14]. Hence, the CLSM mixes designed in this investigation can be used as sub base for lightly loaded structures. Fresh density increases with increases in w/c, c/BA, and bleeding.

Table 5. Strength, Density, and Moisture Content

MIX ID	COMPRESSIVE STRENGTH (MPa)			DENSITY (kg/m^3)			
	7 days	14 Days	28 Days	Fresh	7 Days	14 Days	28 Days
A	0.11	0.32	0.36	1664	1555	1535	1507
B	0.58	0.91	1.12	1449	1428	1416	1435
C	1.09	1.42	2.08	1528	1497	1496	1475
D	1.35	1.73	2.20	1590	1528	1535	1512
E	2.26	3.10	3.93	1688	1635	1625	1509
F	2.95	3.36	4.40	1663	1556	1564	1532
G	2.76	3.46	4.24	1589	1507	1483	1484
H	2.54	3.45	4.23	1640	1544	1545	1566
I	1.23	1.70	2.26	1588	1464	1481	1480

3.2.2. Compressive strength

The compressive strength of CLSM mixes are given in Table 5. The strength at 28 days varies from 0.36 MPa to 4.40 MPa. The compressive strength of non-structural excavatable CLSM should be less than 1.4 MPa [12]. Hence, Mix A and Mix B can be useful in excavatable CLSM in soil filling applications, and all other mixes can be useful in structural CLSM applications like utility bedding. Relationships between strength at 28 days, w/c, and w/(c+k) are shown in Figure 5. As shown in Figure 5, the strength decreases with increase in w/c and w/(c+k). The slope of the linear trend line of w/(c+k) is higher than the slope of the linear trend line of w/c. This is because the addition of kaolin increases the powder content in the mixture and, hence, reduces the water/powder ratio which makes the trend line steeper. The relationship between 28 day strength, c/BA, and (c+k)/BA are shown in Figure 6. Strength increases with age, decreases with w/c and w/(c+k) ratios, and increases with c/BA and (c+k)/BA ratios. The slope of the strength- c/BA chart given in Figure 6 based on the linear trend line is 14.0, whereas the slope for the strength-

(c+k)/BA chart in Figure 6 is 9.4. Reduced slope means reduction in the range of strength values. Hence, it is concluded that kaolin controls the rate of gain of compressive strength. This aspect may be useful in reducing the long term strength development of CLSM.

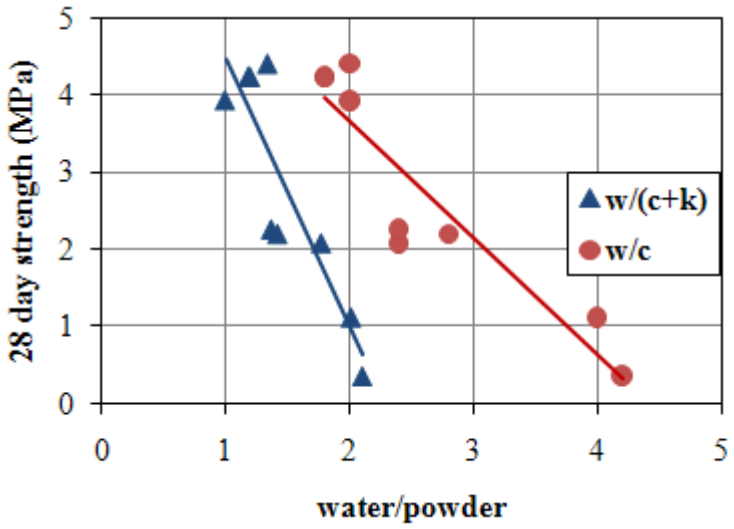

Figure 5: Relationship between 28 day strength and water/powder ratio

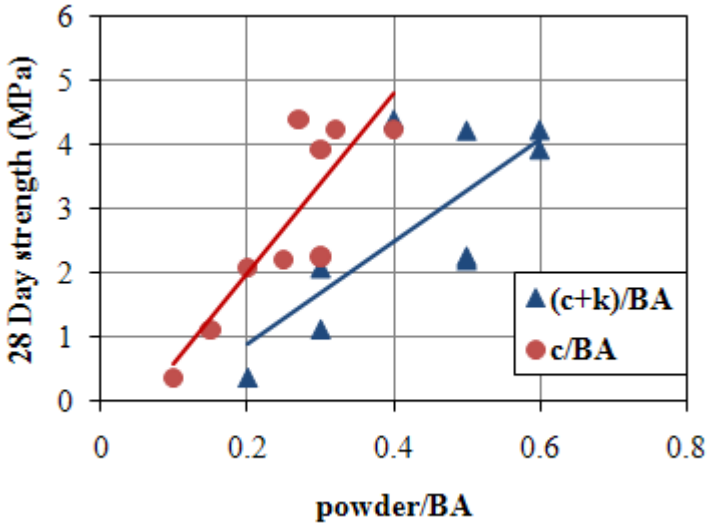

Figure 6: Relationship between 28 day strength and powder/BA ratio

3.2.3. CBR and settlement

CBR is a measure of the supporting value of the sub grade. The CBR values obtained on the CLSM mixes are given in Table 6. The CBR values ranges from 10 to 46. The CBR decreases with increase in w/ (c+k), as evident in Figure 7. Also, CBR increases almost linearly with (c+k)/BA, as shown in Figure 8. A CBR value from 5 to 15 is good and requires no capping [15]. Hence, the performance of CLSM mixtures designed in this investigation is excellent with regard to CBR and, hence, can act as a very good sub grade material. The settlement values of CLSM expressed as a percentage are given in Table 6 and the values of settlement are from 0.8 percent to 2.1 percent at 28 days. This is considered very low for CLSM.

Table 6. Water Absorption, ISAT, CBR, Settlement, and Sorption

MIX ID	WATER ABSORPTION (%)	ISAT (ml/m^2/s)		CBR	SETTLEMENT (%)	SORPTION (m/min$^{0.5}$)	pH	
		10 min	1 hour				Bleed	Leachate
A	29	6.94	4.76	10	na	na	11.7	11.6
B	35	na	na	16	1.9	1.18	11.8	11.7
C	23	3.28	0.84	22	na	0.70	11.2	11.4
D	29	na	na	25	0.8	0.70	11.9	11.8
E	na	1.79	1.12	36	na	Na	12.2	11.3
F	12	1.30	0.69	36	2.1	0.50	12.0	11.6
G	13	1.23	0.56	46	1.4	0.67	12.1	11.9
H	16	1.26	0.56	35	1.1	0.47	12.1	12.4
I	20	2.52	1.45	na	na	0.46	na	11.5

Na = Data not determined

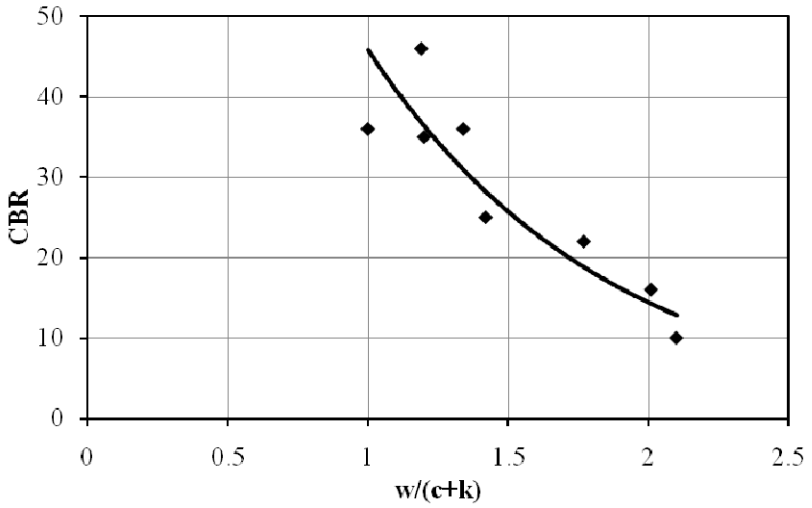

Figure 7: Relationship between CBR and w/(c+k)

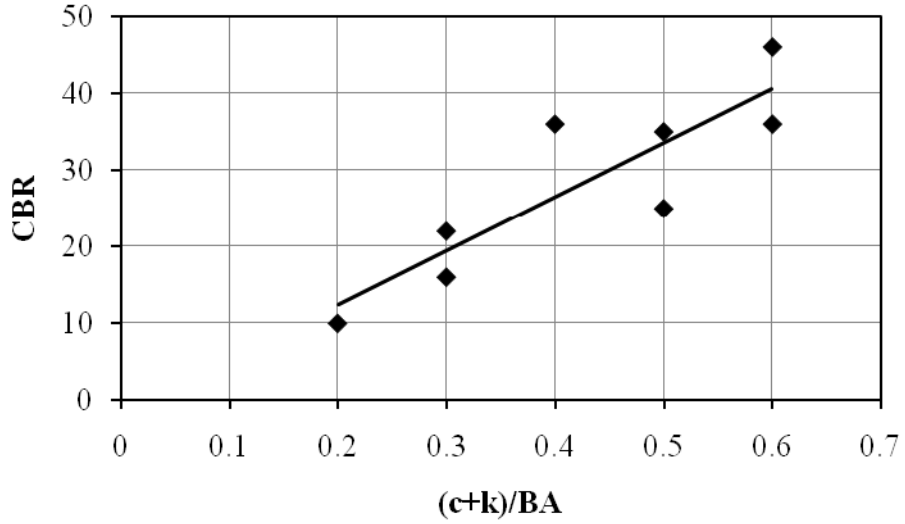

Figure 8: Relationship between CBR and (c+k)/BA

3.2.4. Water absorption, sorption, and initial surface absorption

The values of water absorption, sorption, and initial surface absorption for the CLSM mixes are given in Table 6. The water absorption values range from 12 to 35 percent. It is observed that water absorption increases with increase in w/(c+k) ratio, and decreases with increase in (c+k)/BA ratio, as shown in Figure 9 and Figure 10, respectively. The values of sorption tests conducted on CLSM mixtures are in the range of 0.46 to 1.18 m/min$^{0.5}$. Sorption is also found to increase with an increase in w/(c+k) and decrease with an increase in (c+k)/BA.

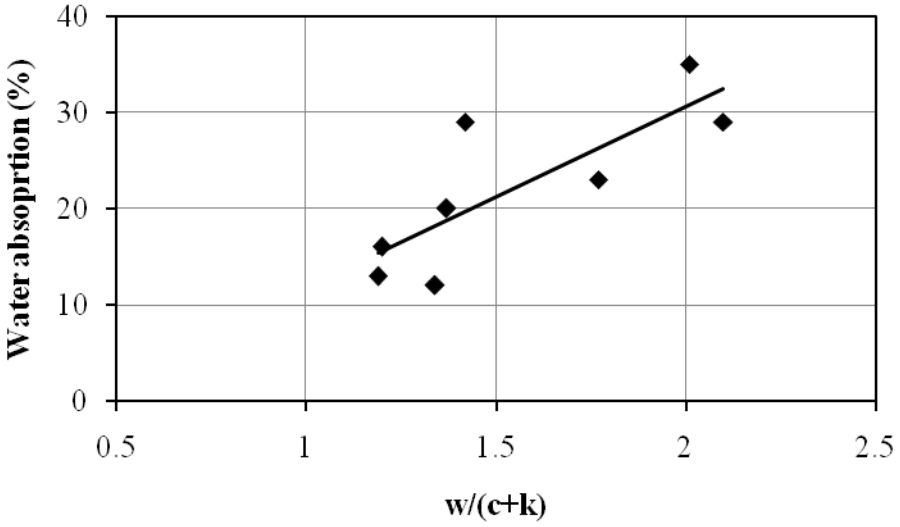

Figure 9: Relationship between water absorption and w/(c+k)

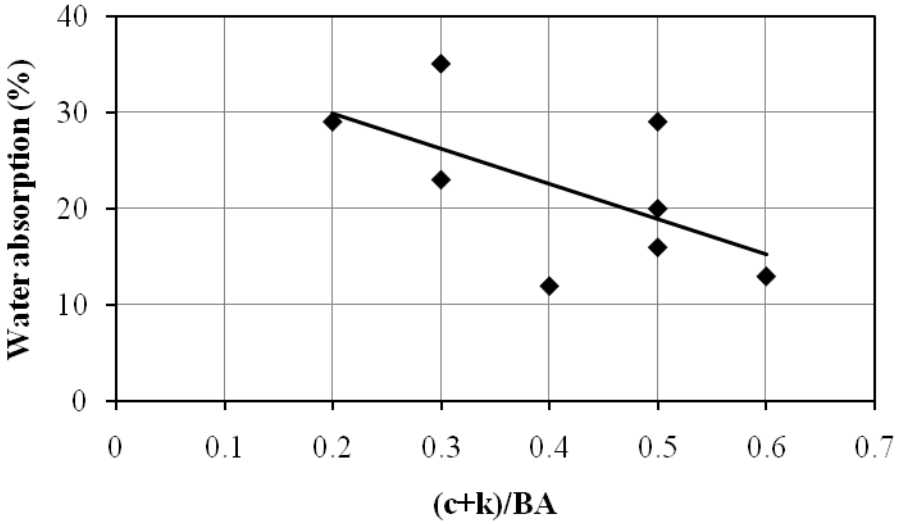

Figure 10: Relationship between water absorption and (c+k)/BA

The ISAT values at 10 minutes for the mixes were observed to be in the range of 1.23 to 6.94 ml/m^2/s. The value of ISAT decreases with an increase in (c+k), as shown in Figure 11. It is apparent that the addition of more powder in the form of cement and kaolin fills the pores and, hence, reduces the ISAT values.

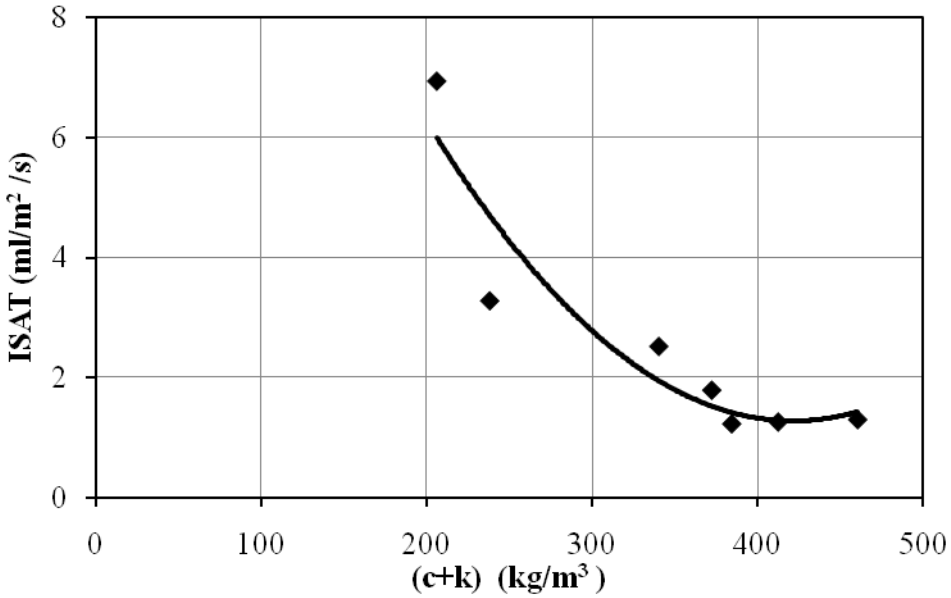

Figure 11: Relationship between ISAT and (c+k)

3.3. Corrosivity

The pH of bleed and leachate samples collected from the CLSM mixtures are given in Table 4. The pH values fall between 11 and 12. This range is neither less than 2.5 nor more than 12.5. Hence, the CLSM does not possess corrosivity. Based on the results available, it is seen that pH of bleed and leachate increases with an increase in c/BA.

3.4. Leaching

The bleed and leachate samples were analyzed for various elements, including heavy metals and salts. The results for bleed samples are given in Table 7 and the results for the leachate samples are given in Table 8. The limits given in Table 7 and Table 8 are based on leaching test recommended acceptance criteria for suitability of industrial wastes for land fill disposal [16]. All the metals tested are well within the limits in bleed and leachate samples except lead and nickel for mixes B, D, and H in bleed. The values of nickel and lead in these three mixtures are clearly outliers, as evident in Table 7. It may be due to pollution caused by external sources during the casting and mixing process. From Table 8, for leachate samples, it is clear that the hardened CLSM is non-hazardous. Also, the concentration of all the elements in the bleed sample is much higher than that of the leachate. It is evident from the test results conducted on bleed that increases in w/c and w/(c+k) reduce the concentration of antimony and potassium. Also, an increase in c/BA reduces the concentration of arsenic, but an increase in c/BA increases the concentrations of chromium, sodium, and potassium. With regard to the results available on leachate, an increase in c/BA is seen to increase the concentration of calcium but reduces the concentration of aluminium.

Table 7. Heavy Metals and Salts in Bleed

NAME	CONCENTRATION IN BLEED (mg/l) IN MIX								LIMIT (mg/l)
	A	B	C	D	E	F	G	H	
Aluminium	83.50	232	64.9	412	46.7	168	40.4	374	
Antimony	0.2	1.18	0.26	0.89	1.98	0.52	0.74	1.19	
Arsenic	0.31	1	0.25	0.88	0.64	0.56	0.29	0.66	5
Barium	6.36	54.1	7.32	49.6	6.26	25.3	12.1	83.4	100
Beryllium	< 0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Boron	1.13	2.42	0.91	2.5	1.46	3.1	1.59	2.94	
Cadmium	0.01	0.01	< 0.01	0.02	0.02	<0.01	<0.01	<0.01	1
Calcium	1410	3290	1490	5880	2160	4650	2010	5550	
Chromium	0.83	2.49	0.54	3.22	1.66	1.91	1.6	5.08	5
Cobalt	0.22	0.58	0.16	0.63	0.1	0.32	0.05	0.82	
Copper	18.5	36.8	9.20	36.7	9.12	19.7	3.14	42.2	100
Iron	168	420	124	504	88	238	29.5	684	100
Lead	2.51	11.8	2.24	10.8	2.01	5.82	1.05	16	5
Lithium	0.03	0.08	0.04	0.14	<0.01	0.1	0.06	0.08	
Magnesium	9.37	29.4	12.2	40.1	6	31.5	3.66	44.9	
Manganese	1.65	5.81	1.63	7.67	1.26	5.48	0.57	9.42	50
Molybdenum	0.38	1.36	0.38	1.26	1.66	0.89	1.53	1.96	
Nickel	2.82	7.28	1.87	7.76	1.24	4.04	0.58	9.16	5
Phosphorous	< 0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Potassium	449	887	412	817	819	1080	1210	1440	
Selenium	< 0.01	0.58	< 0.01	0.55	0.78	0.59	0.6	0.5	1
Silicon	58.1	437	86.5	506	131	237	117	525	
Silver	0.11	<0.01	0.02	0.06	<0.01	<0.01	<0.01	<0.01	5
Sodium	558	1110	457	1200	908	1030	1130	1310	
Strontium	1.80	4.8	1.70	5.66	3.67	5.63	4.36	7.14	
Thallium	3.01	<0.01	2.79	<0.01	0.13	<0.01	0.03	<0.01	
Tin	< 0.01	13.2	< 0.01	8.84	0.89	3.7	0.56	14.7	
Titanium	6.27	22.6	5.03	25.9	3.42	13.7	4.35	36.7	
Vanadium	0.14	0.4	0.11	0.57	<0.01	0.28	<0.01	0.48	
Zinc	8.40	23.4	6.26	23	5.05	13.4	2.28	29.9	100
Total salts	2426	5316	2371	7937	3893	6792	4354	8345	

Table 8. Heavy Metals and Salts in Leachate

NAME	CONCENTRATION IN LEACHATE (mg/l) IN MIX									LIMIT (mg/l)
	A	B	C	D	E	F	G	H	I	
Aluminium	9.09	8.51	2.92	5.24	4.1	3.52	2.88	2.8	18.5	
Antimony	0.37	<0.01	<0.01	<0.01	3.1	0.17	<0.01	<0.01	0.4	
Arsenic	0.1	<0.01	< 0.01	<0.01	0.43	0.12	<0.01	0.09	<0.01	5
Barium	5.73	5.08	0.97	26.3	6.37	10.3	30	10.9	7.9	100
Beryllium	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Boron	<0.01	2.69	0.24	2.02	1.73	2.88	2.35	0.96	5.48	
Cadmium	<0.01	<0.01	< 0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	1
Calcium	177	169	103	263	339	422	360	337	315	
Chromium	0.04	0.05	0.01	0.07	0.04	0.15	0.12	0.04	0.38	5
Cobalt	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	
Copper	0.4	0.58	0.14	0.34	0.49	0.15	0.15	0.18	0.36	100
Iron	<0.01	<0.01	0.35	<0.01	0.35	<0.01	0.86	<0.01	1.62	100
Lead	<0.01	0.53	0.05	0.08	0.17	0.31	0.36	0.49	0.2	5
Lithium	<0.01	0.02	< 0.01	0.02	0.05	0.03	0.02	<0.01	0.05	
Magnesium	0.35	0.92	0.04	0.49	0.48	0.36	0.44	0.38	0.96	
Manganese	0.02	0.03	< 0.01	0.03	0.04	0.02	0.02	0.02	0.09	50
Molybdenum	0.92	0.32	0.14	0.08	1.49	0.27	0.07	0.11	0.32	
Nickel	0.08	0.1	0.01	0.24	0.06	0.06	0.08	0.06	1.37	5
Phosphorous	<0.01	3.3	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Potassium	108	116	52.6	135	127	146	128	140	145	
Selenium	0.22	0.09	< 0.01	0.34	0.82	0.34	0.36	0.13	0.23	1
Silicon	13.3	11.6	6.20	10.5	24.8	16.3	7.38	5.37	50.8	
Silver	0.16	<0.01	< 0.01	3.14	1.56	<0.01	<0.01	<0.01	<0.01	5
Sodium	167	176	51.4	147	125	121	121	122	153	
Strontium	1.15	1.22	0.44	2.15	2.25	2.02	2.19	2.01	2.14	
Thallium	<0.01	0.04	< 0.01	0.07	0.11	<0.01	<0.01	0.07	0.12	
Tin	<0.01	0.28	< 0.01	0.06	0.1	0.07	<0.01	<0.01	<0.01	
Titanium	0.04	0.04	< 0.01	0.07	0.15	0.05	0.03	0.02	0.59	
Vanadium	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Zinc	0.29	0.56	0.12	0.74	0.47	0.26	0.41	0.25	1.39	100
Total salts	452	462	207	545	591	689	609	599	614	

4. CONCLUSIONS

The purpose of this study was to investigate the performance of industrial waste incineration bottom ash and refined kaolin in CLSM. Based on the completed investigation, the following conclusions are drawn:

- The initial setting time for the CLSM mixtures is in the range of 6.5 hours to 9.25 hours. Hence, additional layers of CLSM can be allowed after this time period. Adding more kaolin is seen to control the variation range of initial setting time.
- The CLSM mixes designed in the investigation are stable as the bleed for all the CLSM mixes is less than one percent.
- The compressive strength of CLSM mixes tested is in the range of 0.36 MPa to 4.40 MPa. This shows that CLSM using incineration bottom ash and kaolin can be designed for excavatable and structural filling applications like soil and structural filling, utility bedding, and sub-base. Both w/c ratio and c/BA ratio influence the compressive strength of CLSM. Addition of kaolin reduces the rate of gain of strength.

- The hardened density values of CLSM mixes are in the range of 1435 kg/m^3 to 1566 kg/m^3 , which is comparable to that of sand and sandy loam soils.
- The CBR values for the hardened CLSM range from 10 to 46, which is seen to be very good for sub base applications. Also, the settlement of CLSM was observed to be less than 2.1 percent, which means that the CLSM poses no settlement problems.
- The water absorption and sorption are seen to increase with an increase in w/(c+k) ratio, and decreases with an increase in (c+k)/BA ratio. The ISAT values are seen to decrease with an increase in cement and kaolin contents.
- The CLSM produced does not have corrosivity from the aspect of pH of bleed and leachate. The hardened CLSM is non-hazardous as all the contaminants tested on the leachate are well within the limiting values. The concentration of contaminants is more in bleed than the concentration of leachate.
- Based on this investigation, it is concluded that industrial waste incineration bottom ash can be successfully used in CLSM along with kaolin.

ACKNOWLEDGMENT

The authors wish to thank the Ministry of Science, Technology and Innovation (MOSTI) and University of Malaya for providing the funds to support this research work. The support given by the management of Kualiti Alam Sdn Bhd, Malaysia for supplying the bottom ash and extending their laboratory facilities for completing this research successfully is also acknowledged.

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