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Study of permeability and unconfined compressive strength of GGBS-cement-lime mixtures modified by further Bentonite

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ABSTRACT: Slurry walls as vertical barriers, employed in geoenvironmental remedial applications, are used to minimize flow rate of the subsurface contaminant contained. In most applications, backfill material involve two basic types of slurry; (1) soil-bentonite (SB) and (2) cement-bentonite (CB), beneficial effect of which is defined by nature of the project. In addition, supplementaries as barrier material such as Ground Granulated blast furnace slag (GGBS) can also improve the mixture properties as backfill material.This paper presents Flexible Wall permeameter test results for determination of permeability, *k*, and unconfined compressive strength, q_u, of cured specimens with different mixing percentages. 20% of weights of all samples are cementitious material which has been mixed by 80% bentonite-water slurry. Thereafter, cementitious materials are replaced by 5% lime and around 50% GGBS as supplementary material instead of Portland cement for all tests. Alternatively, mixing of the cementitious material by bentonite-water slurry that contains 5 and 9% (by dry weight) of sodium bentonite, were also prepared to have slump of 4 to 6 inches. Unconfined compression tests were carried out on samples with 7 and 28 days curing and showed increase of 117 kPa due to replacement of 5% lime 28 days curied samples. Moreover, the permeability tests were carried out under confining stress of σ'_3=100 kPa on the same specimens and results showed improvement in permeability from 2.77× 10^{-7} cm/s and 5.95×10^{-7} cm/s to 8.77×10^{-7} cm/s of that of corresponding samples without lime replacement.

1 INTRODUCTION

Slurry walls are operating as in situ remediation systems to confine the contaminant movements through the surrounded area, Fig. 1 revealed typical cross section where investigated material used in wall section.

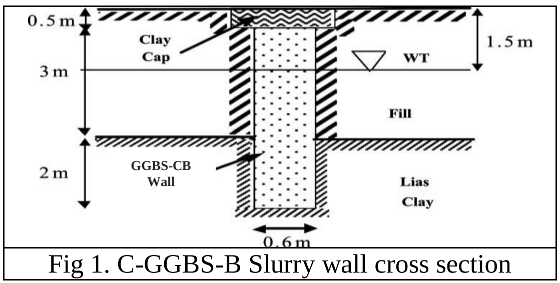

Fig 1. C-GGBS-B Slurry wall cross section

These walls are constructing by low permeation material to reduce the groundwater streams into the encapsulated area to preclude contaminant migration in the way of groundwater. The most common type of self hardening slurry material; Cement-bentonite (CB) are typically limits the hydraulic conductivity of walls not less than 10^{-6} cm/s, thus this permeation results are not enough for acceptable permeability ranges for minimum of 10^{-7} cm/s in contaminated area. Besides, some beneficial properties of industrial waste such a ground granulated blast furnace slag (GGBS) that could be added to the cement as a part of cementitious supplementary system, can utilize with the purpose of permeability reduction. In addition, natural pozzolans as slurry wall materials are increasing wall resistance to chemical attack, alkaline reactivity and etc. These are supplementary that reveal reactivity with lime and water so in order that they get, harden and achieve more strength and diminish permeability (Massazza 1977). This paper aims to investigate the effect of 5% lime and around 50% of two different types of GGBS replacement by cement as slurry wall material. Permeability and unconfined compressive strength test were investigated for 7 and 28 days curing time for samples. Moreover, all mixtures were blended by two different percentages of bentonite-water slurry. 5% and 9% of bentonite by mass was mixed by distilled water as batches slurry while the other 20% is consist of cementitious material. Also, by increasing of bentonite content for second mixtures, samples shows better result with lower hydraulic conductivity and even higher shear resistance. At present, there is no certain method gives for the illustration of the required parameters of GGBS-CB wall (Manassero 1994; Tedd et al. 1997; Ratnam et al. 2001). All samples have been cured in 100% humidity environment and were subjected to flexible-wall hydraulic conductivity and unconfined compressive strength tests.

Materials

Materials used for this study are shown in Fig. 2.

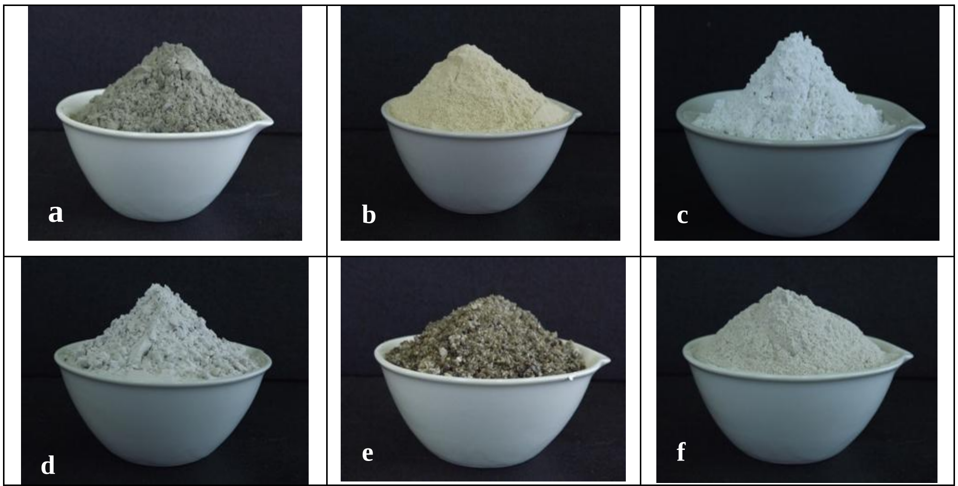

Fig 2. Material used for this study, (a) cement, (b) bentonite, (c) lime, (d) GGBS type I, (e) GGBS type II before grinding, (f) GGBS type II after grinding

Portland cement

Rapid strength Portland cement-type I in accordance to (ASTM C150), by specification of CEM I, 42.5R, K (95-100) has been used as cement part of the cementitious materials (Fig. 2(a)). Rapid strength gain rate in this kind of cement has increased by the time was rather than normal CEM I would help to achieve early strength of specimens and allowed to test of 7 days curing time.

Bentonite

Karakaya powdered sodium bentonite was used for this investigation (Fig. 2(b)), and the mineralogical compound and engineering properties of the bentonite are given in Tables1 and 2.

Lime

Strictly speaking, lime is common expression for inorganic material consist of calcium where hydroxides and carbonate oxides are in the majority (Fig. 2(c)). Lime is still in utilizing in large quantities as engineering material. Lime can reduce the swelling potential of the wet bentonite. Also there could be a significant permeability modification as well because of lime supplement to liner materials, laboratory investigation showed liner permeability reduction by two orders of magnitude after lime adding (ASTM-STP 874).

Ground granulated ballast furnace slag (GGBS)

Sand size of GGBS manufactured in factory was grinded in ball mill grinding operation for 3 hours to achieve silt size of this material in laboratory. Sieve analysis shows all material passed sieve number 100 and only 30% remains on number 200. Two kind of GGBF were tested in this study obtained from different places in Turkey (Fig. 2(d), (e) & (f)). Furthermore, the GGBS-CB materials can be deterioration due to drying procedure (Joshi et al. 2008), and cracking occurred in toward the top level of slurry walls soon after construction is a remarkable phenomenon. A coefficient of hydraulic conductivity value of 10^{-6} cm/s, which could be suitable for the demanded maximum value for water-retaining structures, was achieved by the addition of GGBS.

Table 1. Engineering properties of Karakaya bentonite (Kayabali 1996)

Parameter	Value
Dry density(Mg/m^3)	0.8
Natural density(Mg/m^3)	0.87
Water content (%)	8
Specific gravity	2.25
Void ratio (%)	1.89
Porosity (%)	65
Liquid limit (%)	320
Plastic limit (%)	50
Cation exchange capacity (meq/100 g)	55-60

Table 2. Mineralogical compound analysis from X-ray diffraction of Karakaya bentonite (Kayabali 1996)

Mineralogical compound	Weight %
Quartz	5
Zeolite	19.5
Smectite	71
Others	4.5

Procedures

Bentonite-Water Base Mixtures

Bentonite-water slurry was prepared by two different mixtures (5 and 9% of dry weight bentonite by distilled water) as base slurry, respectively. It is mixed by an electrical high-speed mixer for 5-10 minutes then the slurry was allowed to hydrate for a week before it was used (this long period of time for hydration was due to having of homogeny and viscous slurry). During these 7 days slurry was mixed by high-speed mixer for 2 minutes every two days. The measurement of distilled water pH at 22˚C temperature was 6.96 and bentonite-water slurry by bentonite content of 5 and 9% were 9.1 and 8.87 at 19.5˚C respectively.

Sample preparation and experiments

Two different mixtures of bentonite-water slurry were prepared for mix designs, the initial one for first step and the second one for modifying of optimum results of first step by extra content of bentonite and 5% lime replacement as well were added. At 7 days, slag content had slight effect on the compressive strength, whereas samples permeability at the curing time of the 28 and 91 days reduced by the slag content increased. The influence of slag replacement of 50% has better effect on compressive strength rather than more replacements (Nakamura et al 1992). All of samples were prepared with 95 and 91% (by weight) distilled water and 5 and 9% sodium bentonite as 80% of based slurry. Lime contained mixtures were considered for these two slurry assortment for GGBS influence of 50%. While the other batches of slurry without lime in first step were only mixed by 5% of bentonite batches. Five liter of bentonite-water slurry batches were mixed for each time and kept in a gallon bucket and left to hydrate for sample preparation day. In the days of mixing, three kg of based slurry was separate and blend with cementitious material. Both of Portland cement and ground granulated blast furnace slag as 20% cementitious material were mixed by based slurry according to mix designs. Even though some sediment may be develop into the GGBS-CB in the field, no mass of soils were blended to the laboratory samples as it is considered these materials do not substantially change the properties of the GGBS-CB (Opdyke and Evans 2005). For sample preparation, 750 g of dry cementitious material was passed sieve number 40 for five times having good quality of dry mix. Then after, three kg of batches slurry were added to dry material and mixed by hand using steel spatula in a plastic container for five minutes to reach uniform slurry. Provided mixtures were placed in the plastic molds having 10 cm of length, 5 cm inner diameter and 6.3 cm of outer diameter. Cured specimens shows the shrinkage problem in height because of high water content of the samples, to solve this problem thin cylindrical plastic with the diameter of 5.5 cm and length of 3 cm were stick on all molds for achieve 10cm of height and were cured in 100% humidity room at temperature (20±2˚), hence in the test days thin supported plastic as well as additional material over the molds were cut carefully. Permeability was measured using Flexible-wall permeameters test. It was used to measure k value in accordance with the method E constant volume-constant head described in ASTM D5084-03. The specimen is surrounded by a rubber membrane and filter papers are placed at two ends between the porous stones and specimen. The membrane has fastened the specimen to the pedestal from the bottom up to the top cap by plastic rings. A backpressure of 100 kPa was applied to expel of entrapped air in the samples and system. Saturation procedures were implement by applying backpressure and confining stress of σ_3=100 kPa for 24 hours. The backpressure was applied using at least for 15-min intervals and increased between 35 and 75 kPa, such that the variation between cell pressure and backpressure at all time was not as much of the desired effective consolidation stress to lessen the potential in the case of over consolidation of the sample (Opdyke and Evans 2005). Before permeability tests, the value of the pore water pressure parameter *B* is determined by: $B=\Delta u/\Delta\sigma_3$ where $\Delta\sigma_3$ is cell pressure increase and Δu is the change of pore pressure due to cell pressure increment. The coefficient of *B* value observed from the pore pressure changes due to cell pressure increment of 100 kPa and was illustrated using Skempton pore pressure coefficient B (Skempton 1954). To perform permeability tests, $B \geq 0.95$ was considered as saturation criteria. Determination of saturation rate took several hours until B value of ≥ 0.95 was reached according to standard. The saturation backpressure applying is remains steady in the procedure of permeability test (Oweiss, S, and Khera, Raj P. 1998). Cell pressure of 100 kPa and backpressure of <100 kPa were applied to permeability measurement. Minimum five significant digits of influent and effluent were recorded. Permeation measurements for the tests continue in anticipation of minimum last two significant steady records of the *k* value. Permeation applied by backpressure from bottom of the specimen also create desired gradient across the sample and induce to bring out of the entrapped air along the specimen. All samples were subjected to hydraulic conductivity test until equilibrium records was achieved. Typically it takes two or three days but no longer than four days. Furthermore, for the same curing time of the samples by following the same mixtures in the permeability test also were subjected to unconfined compression test. Two samples of the specimens in cured day were tested for the q_u test. Samples in the molds were extrude by electrical hydraulic device and used for the unconfined compressive strength in accordance to ASTM D2166-06. Similar specimen sizes were used in the unconfined compressive strength test having diameter of 5cm and 10cm in height by using the height-to-diameter ratio of 2 in accordance to standard as mentioned above. Specimens were placed in loading device in the center of the bottom plate so that loading device was adjusted carefully on the specimen to distribute the applied stress.

Results and discussion

Specific Gravity

Determination of the mixtures Specific Gravity (G_s) were followed (ASTM- C188-09) Standard Test Method for Density of Hydraulic Cement. This standard was prepared for specifying cement, if any, associated for other pozzolans G_s quantities. Material usage in this study start to hydrate while mixing with water and particles volume will be changed during hydration. This is straightly why this method was selected for G_s specification. Kerosine having a density greater than 0.73 g/mL at 23 ± 2° C used for volume change determination in flask for this procedure. Table 3 gives the relevant values of G_s for each mixture as 20% cementitious material with two kind of ground granulated blast furnace slag. This test demonstrated that G_s value of mixed material is affected intensely by each materials specific gravity value.

Table 3. Atterberg limit and G_s values of mixtures.

Material	Bentonite content (%)	Mixture	Replacement (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	G_s
GGBS Type I	5	CS	(100-0)	39.40	25	14.40	2.82
		CS	(80-20)	40.30	25.70	14.60	2.80
		CS	(50-50)	42.25	27	15.25	2.76
		CS	(20-80)	40.45	23.20	17.25	2.73
		CSL	(50-45-5)	42.60	26.10	16.50	2.73
		CSL	(45-50-5)	41.20	23.50	17.70	2.66
	9	CSL	(50-45-5)	62	24	38	2.70
		CSL	(45-50-5)	57.10	27.4	29.70	2.63
GGBS Type II	5	CS	(80-20)	39.90	23.20	16.70	2.78
		CS	(50-50)	38.2	22	16.20	2.79
		CS	(20-80)	37.50	19.70	17.80	2.70
		CSL	(50-45-5)	37.15	23	14.15	2.76
		CSL	(45-50-5)	39.90	22.30	17.60	2.74
	9	CSL	(50-45-5)	51.80	20	31.80	2.76
		CSL	(45-50-5)	49	20.15	28.85	2.68
Cement	0	C	100	-	-	-	2.89
GGBS- I	0	S	100	-	-	-	2.86
GGBS-II	0	S	100	-	-	-	2.84
Lime	0	L	100	-	-	-	2.27
Bentonite	100	B	100	-	-	-	2.17

Note: CS=Cement-GGBS; CSL=Cement-GGBS-Lime

Atterberg Limit

To cover the determination of the liquid limit, plastic limit, and the plasticity index of the mixtures, wet preparation method in accordance of ASTM D4318-10 was tested. Prepared samples did not allow to stand (cure) for minimum 16 hours (overnight) because of materials specifications and reactions with water during elapsed time. 200 g of dry weight of each mixture (no material retain on 425-μm (No. 40) sieve) was mixed by thoroughly distilled water with hand using steel spatula for 5 minutes. Table 3 shows the result of Atterberg limits and G_s as well.

Hydraulic conductivity

The results of flexible-wall permeability tests are given for effect of two types of GGBS add to the samples (see Fig. 3). Replicate samples prepared by different replacements as shown below gives the final hydraulic conductivity results for 7, 28, and 90 days of curing. In addition, the *K* value for the GGBS influenced by 50% for three month curing time is in the typical standard limit of 10^{-7} cm/s for in situ contaminated sites application as well. Similar permeability tests were also investigated on type II of GGBS. Values of the permeability tests are in the range of 2.36×10^{-6} to 1×10^{-6} cm/s for GGBS replacement type I and from 1.66×10^{-6} to 1×10^{-6} cm/s for GGBS type II for 7 and 28 days of curing time, respectively. A substantial reduction of hydraulic conductivity is reached with the suitable GGBS replacement by the end of 28 days curing. It is important to see in Fig. 3, samples having 50% addition of GGBS gives the optimum results for permeability test for one month curing over all. Also the specimen by 90 days of curing for GGBS type one gives the permeability of 8.20 × 10^{-8} cm/s. However, Fig. 3, illustrate the effect of curing time of the samples on permeability outcomes. Type of GGBS related to the chemical and physical properties has also effect on hydraulic conductivity of the samples. Moreover, investigation on 50% GGBS replacements were also carried on by mixture amended with 5% lime replacement and further bentonite usage in batches, respectively.

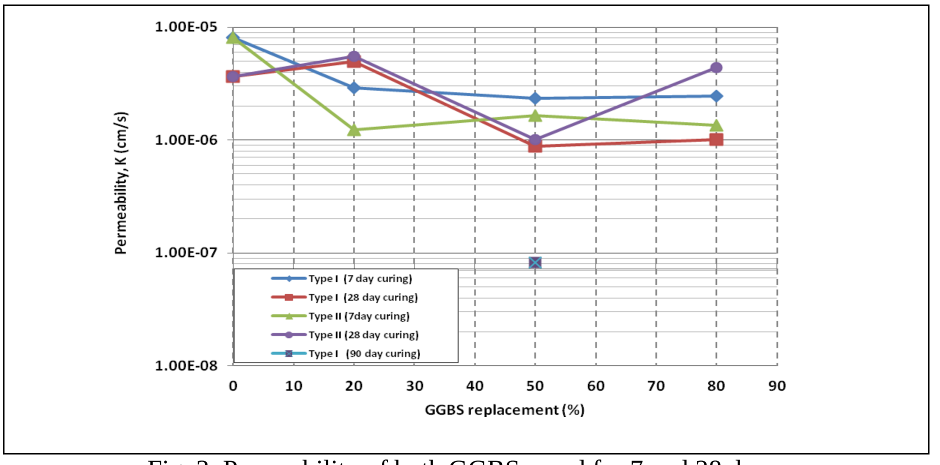

Fig. 3. Permeability of both GGBS cured for 7 and 28 days.
(bentonite content 5%)

Table 4 gives advantageous outcomes of permeation test for modified mixtures. Permeability range of 10^{-7} cm/s were achieved in some of the mixtures for 28 days curing and even for GGBS type II amended by 9% bentonite content for 7 days curing. By the results demonstrated above, addition of 5% replacement of lime according to mix designs only reduced permeability of 28 days curing for GGBS type II. On the other hand, increasing of bentonite content to 9%, decrease hydraulic conductivity values for all amended mixtures for both curing times.

Table 4. Amended mixtures permeability results.

Mixture number	Bentonite content(%)	GGBS types	Mixture design	Replacement (%)	Permeability k(cm/s) 7 Days	28 Days
1	5	I		(50-45-5)	4.49E-6	9.77E-6
2	5	I`		(45-50-5)	3.46E-6	4.97E-6
3	9	I		(50-45-5)	1.06E-6	2.77E-7
4	9	I	(C-S-L)	(45-50-5)	1.55E-6	5.95E-7
5	5	II		(50-45-5)	2.60E-6	9.93 E-7
6	5	II		(45-50-5)	4.46E-6	8.82E-7
7	9	II		(50-45-5)	5.97 E-7	2.77E-7
8	9	II		(45-50-5)	5.82E-7	7.01E-7

Note: (C-S-L)=Cement-GGBS-lime

Unconfined compressive strength

The experimental testing program revealed different affiliation between q_u and GGBS replacement for two types of this material. GGBS content of 55% the unconfined compressive strength were increased at prior ages and minor at later age (Tomisawa, Chikada, and Nagao 1992). Fig. 4 presents the q_u test outcomes for two different GGBS. Similar to illustrated results for GGBS of 50% replacement for permeability tests outcomes, remarkable value is also obtained for 28 days of curing for GGBS type I. On the contrary, unconfined compressive strength of GGBS type II decreased by increasing of GGBS replacement. Besides, amended mixtures by lime and additional bentonite content were investigated as illustrated above. Table 5 gives the unconfined compressive strength results of cured samples where the strengths decreased by addition of lime content while they are increasing by additional bentonite content.

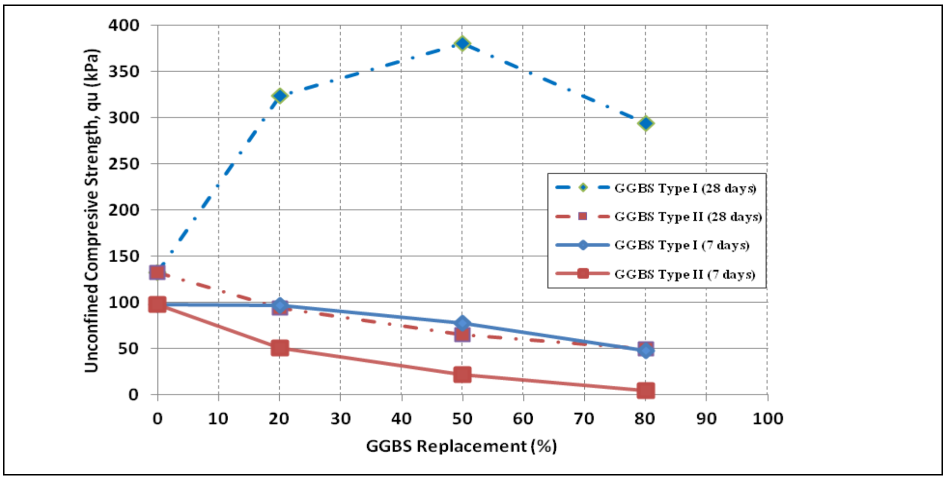

Fig. 4. Unconfined compressive strength of both GGBS (bentonite content 5%)
Note: GGBS=Ground granulated blast furnace slag

Table 5. Amended mixture unconfined compressive strength results.

Mixture number	Bentonite content	GGBS types	Mixture design	Replacement (%)	Unconfined compressive strength(kPa)	
					7 Days	28 Days
1	5	I		(50-45-5)	32	286
2	5	I`		(45-50-5)	32	193
3	9	I		(50-45-5)	80	505
4	9	I	(C-S-L)	(45-50-5)	54	393
5	5	II		(50-45-5)	17	50
6	5	II		(45-50-5)	14	47
7	9	II		(50-45-5)	58	205
8	9	II		(45-50-5)	67	225

Note: (C-S-L)=Cement-GGBS-lime

Conclusion

The aim of this research, via laboratory testing, studies the effects of two types of GGBS, lime and bentonite influences on k and q_u values as slurry wall material. The effect of curing condition on the permeation and strength of specimens present the better values by the time passed. The test outcome shows the better effect of 50% GGBS replacement on specimen durability. Furthermore, lime has advantage for GGBS type II for 28 days curing for permeability tests. It is important to note that which of the key factors of (k or q_u) is decided to choose an important roles. For instance, samples having higher GGBS replacement generally show better results for permeability in long term of curing time, while 50% influence of this material gives higher shear strength particularly when mixture amended by lime. On the other hand, if these two factors considered simultaneously, this investigation shows that the influence of 9% bentonite content by addition of lime for GGBS-CB mixtures gives acceptable results for one month curing.

References

ASTM, Standard C150/C150M – 11, "Standard Specification for Portland Cement," ASTM International,West Conshohocken, PA.

ASTM, Standard C188 – 09, "Standard Test Method for Density of Hydraulic Cement1," ASTM International,West Conshohocken, PA.

ASTM, Standard D2166-06, "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil," ASTM International, West Conshohocken, PA.

ASTM, Standard D4318-05, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils,"ASTM International, West Conshohocken, PA.

ASTM, Standard D5084-03, "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a FlexibleWall Permeameter,"ASTM International,West Conshohocken, PA.

Johnson, Frobel, Cavalla, Pettersson. (1985). "Hydraulic Barriers in Soil and Rock."*ASTM STP No. 874*, ASTM International, Philadelphia, PA.

Jefferis, S. A. (2008). "Reactive transport in cut-off walls and implication for wall durability." Proc., GeoCongress 2008: The Challenge of Sustainability in the Geoenvironment, ASCE, Reston, Va., 652–659.

Manassero, M. (1994). "Hydraulic conductivity assessment of slurry wall using piezocone test." J. Geotechnical Engineering, 120(10): 1725–1747.

Massazza F, Costa U. (1977). "Factors determining the development of mechanical strength in lime-pozzolana pastes" Proceedings of the XXII Conference on Silicate Industry and Silicate Science, Budapest, Vol. I: 537-52.

Nakamura, N. Sakai, M., and Swamy, R.N. (1992). "Effect of Slag Fineness on the Development of Concrete Strength and Microstructure." 4th International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Istanbul, May 1992. vol. II: 132-72.

Opdyke, S. M., and Evans, J. C. (2005). "Slag-cement-bentonite slurry walls." J. Geotechnical. Geoenvironmental engineering. 131(6): 673–681.

Oweiss, S, and Khera, Raj P. (1998). "Geotechnology of waste management" 2nd Edition, PWS Boston Publishing.

Skempton, A. W. (1954) "The pore pressure Coefficient A and B," Geotechnique, (4): 143-47.

Tomisawa, T. Chikada, T. and Nagao, Y. (1992). "Properties of Super Low Heat Cement Incorporating Larg Amounts of Ground Granulated Blast Furnace Slag of High Fineness." 4th International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Istanbul, Vol. II: 132-74.