App. Envi. Res. 36 (2): 61-68

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/jer

Utilization of Cellular Glass Insulation Waste in Construction Materials

Thitikorn Buasomboon and Orathai Chavalparit *

Department of Environmental Engineering, Faculty of Engineering,
Chulalongkorn University, Bangkok 10330, Thailand
* Corresponding author: E-mail: orathai.c@chula.ac.th

Article history
Submitted: 1 September 2013/ Accepted: 20 December 2013/ Published online: 24 March 2014

Abstract

This research investigated the feasibility of using cellular glass insulation waste as fine aggregate in concrete paving block production. The effect of mixing proportions of cellular glass insulation waste at 0-40% by volume was studied. Results show that the amount of cellular glass waste can be used as a substitute for fine aggregate or sand up to 20%. Concrete specimens tested for compressive strength were found to be within an acceptable range of the interlocking concrete block paving standard set by Thailand Industrial Standards Institute. The compressive strength at 28 days was 41.50 MPa, with density ranging from 2.18 to 2.20 g/cm^3. Thus, recycling of cellular glass wastes for concrete paving block production can reduce expenditures in purchasing natural aggregates and can minimize environmental impact attributed to solid waste disposal**.**

Keywords: Cellular glass waste; recyclable waste material; fine aggregate substitute; interlocking concrete paving block

Introduction

Cellular glass is a lightweight and porous glass material, used for insulation of cold, hot and burned pipes for acoustic insulation [1], as well as many industrial applications. Cellular glass is widely installed for cold insulation and cold storage, and any process or warehouse requiring cooling systems, for example in the food, petro-chemical and transport industries. Scheduled maintenance programs and accidental leakage are considered to be the main sources of this insulation waste. Insulation waste from the petrochemical industry is classified as hazardous waste since it is frequently contaminated with oils or chemicals. This waste is usually disposed of by landfilling, which is not an environmental-friendly solution. Reuse/recycling of cellular glass waste is therefore considered a more sustainable approach in order to avoid environmental problems.

Traditional construction materials are produced from natural materials which have been continuously over-exploited. Manufacture of many construction materials also generate local air and water pollution. Production costs are increasing because of increasing demand scarcity of raw materials, as well as the increasing cost of energy [2].

From the standpoint of energy saving and conservation of natural resources, use of alternative raw materials such as solid wastes in construction materials offers global benefits. Many types of solid wastes have been studied for thier utility in production of construction materials. Both hazardous and non-hazardous waste from various sources such as agriculture, industry and mining have potential for recycling in construction materials [3]. At present, there are several applications of solid waste based construction materials in real construction such as the use of fly ash and blast-furnace slag as components of concrete; rice husk ash and palm oil fuel ash for interlocking blocks, bottom ash and quarry waste for aggregates [4, 5, 6, 7, 8, 9]. Fly ash obtained from coal combustion is frequently used in concrete as a cost-effective substitute for portland cement. In addition, the pozzolanic properties of fly ash improve the strength of concrete. The level of fly ash in concrete typically ranges from 15% to 35% of total cementitious material, but a substitution level up to 70% is possible in construction of massive walls, girders, road bases, and dams [10]. GGBF slag, a by-product from iron and steel industry, can be utilized for making portland slag and supersulfated cements. The use of ground granulated blast-furnace slag with cement improves the microstructure, final strength, and durability of hardened concrete [11]. The level of GGBF slag usually ranges from 25% to 50%. Rice husk ash from burning of rice husks between 500 and 800°C possesses excellent pozzolanic activity due to its high surface area and high silica content. The use of rice husk ash improves the compressive, tensile and flexural strengths of concrete and also improves its corrosion resistance and freezethaw durability [12]. Quarry waste is a by-product from the crushing process of rocks. Quarry waste can be used as a substitute of sand in construction materials.

In recent years, the construction industry has steadily introduced initiatives to improve sustainability by increasing use of recycled and/or manufactured aggregates in concrete production [13]. Different types of insulation wastes have also been reported as possible recylable materials for substitution of fine and coarse aggregates or cementitious materials for concrete production. Insulation wastes have also been added in concrete for improving the quality and properties of concrete [14]. Several research works have been conducted to evaluate and investigate the potential of using insulation waste in concrete production. Cheng et al. showed that rock wool waste could partially replace fine and coarse aggregates in concrete [15]. Sengul et al. studied the use of perlite as a replacement for fine aggregates in making lightweight concrete [16]. Ma et al. studied the addition of ceramic wool in concrete to enhance its tensile properties [17]. However, no studies have yet been conducted on the use of recycled cellular glass insulation waste (CGIW) in concrete production. Therefore, the objective of this study was to investigate the ultimate compressive strength of concrete and the utility of cellular glass insulation waste as a component in interlocking concrete paving block production, as a substitute for fine aggregates and cementitious material.

Experimental program

1) Preparation of materials

The raw materials used in this study are cement, fine aggregate or sand, coarse aggregate or rock, water and cellular glass insulation waste (CGIW). The characteristics of each raw material are described below.

Cement: The cement used was ordinary Portland cement in dry powder form, with typical chemical composition as listed in Table 1. Portland cement compliant with ASTM C150 [18] was used for concrete production.

Fine aggregate: Sand used in this study complied with the grading requirements of overall limits as specified in ASTM C33 [19].

Table 1 Chemical compositions of CGIW, fine aggregates, coarse aggregate and cement

Chemical composition (%)	**CaO**	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**MgO**	**TiO**	**Na_2O**	**K_2O**	**SO_3**	**Cl**	**Other**
Portland cement	63.82	20.20	2.92	5.42	1.50	-	0.26	0.46	2.55	-	2.87
Fine aggregates	5.33	88.54	0.76	1.21	1.55	0.05	0.33	0.31	-	-	1.92
Coarse aggregate	0.26	97.03	0.10	0.34	-	-	0.16	-	-	-	2.11
CGIW	4.67	59.32	2.62	4.24	3.55	0.04	18.43	1.63	2.53	0.05	2.92

Figure 1 CGIW from deterioration

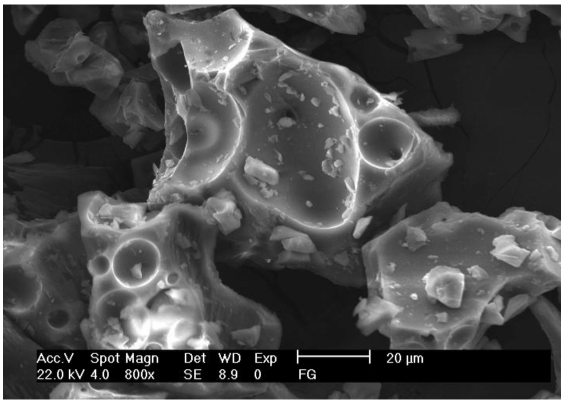

Figure 2 SEM micrograph of CGIW surface

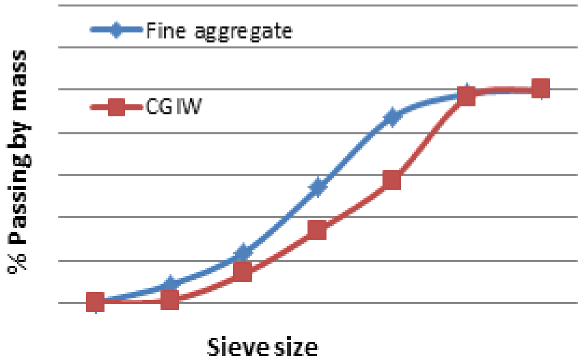

Figure 3 Size distribution of CGIW and fine aggregates

Fine aggregate: Sand used in this study complied with the grading requirements of overall limits as specified in ASTM C33 [19].

Coarse aggregate: Stone used in this study complied with ASTM C33 method [19].

Cellular glass insulation waste: The CGIW used in this study was obtained from deterioration or debris demolition from a petrochemical plant as shown in Figure 1. Prior to experimenttation, CGIW was crushed and grounded by a grinder. Figure 2 shows a micro-structure of CGIW. The structure revealed concave surface with many pores. The result of particle size distribution analysis of CGIW according to ASTM C136 method [20] is shown in Figure 3. The result from sieve analysis of the cellular glass waste shows the size distribution ranging between 150 and 300 µm., which is similar to fine aggregates. The particles were passed through the sieve of 1.18 mm, which is found to be similar to sand size that is used in mortar mixes. The study was conducted to characterize the material using chemical composition analysis and x-ray fluorescence (XRF) analysis. The leaching toxicity characteristic of the cellular glass waste and concrete paving block were also determined by waste extraction test (WET) method [21].

2) Mixing proportions

The concrete mix of cement, rock and sand was prepared with a ratio of 1:1:2. The water : cement ratio was kept constant at 0.5 for all specimens in this experiment. Cube samples were cast in metal moulds with a dimension of 50 x 50 x 50 mm. These samples were also used to determine the compressive strength in a wet curing method. CGIW was used to partially replace sand by 0%, 10%, 20%, 30% and 40% by volume. Table 2 shows the mixing proportions.

3) Specimens

A total of 250 specimens for 5 different mixes included 1 set of control and 4 sets of tested specimens having the CGIW amount of 10% - 40% by volume of sand. After setting for 24 h, the specimens were removed from the moulds. All specimens were then cured in water at room temperature until testing. Five of them were prepared for each constituent proportion and curing condition and they were tested for compressive strength, density and water absorption at 7, 14, 28, 42 and 56 days. Data were reported by averaging result of 5 replicates. For concrete paving blocks, the optimum proportion obtained from the cube specimens experiment was used. The mixes were casted in the 110 mm x 65 mm x 250 mm moulds.

4) Testing methods

The specimens were cured for a certain period for a test of compressive strength according to TIS 827-2531 method [22], and density and water absorption were tested by the ASTM 642 method [23].

Result and discussion

1) Chemical composition of CGIW

The CGIW was characterized with high silicon oxide of 59.32% compared with sand, but the CGIW showed the less SiO_2 content. Table 3 presents comparison of chemical properties CGIW and the pozzolanic class set by ASTM C618 [24].

Table 2 Mixing proportions of concrete mix design (kg/m^3)

Mix No.	Sand: CGIW (by volume)	Cement (kg/m^3)	Sand (kg/m^3)	CGIW (kg/m^3)	Rock (kg/m^3)	Water (kg/m^3)
C0	100: 0	512	512	0	1,023	256
C10	100: 10	512	486	26	1,023	256
C20	100: 20	512	461	51	1,023	256
C30	100: 30	512	435	77	1,023	256
C40	100: 40	512	410	102	1,023	256

Table 3 Comparison of chemical composition of CGIW and pozzolanic material classified by ASTM C618

Properties (%)	Pozzolanic class			CGIW
	N	F	C	
$SiO_2 + Al_2O_3 + Fe_2O_3$, min	70.0	70.0	50.0	66.18
SO_3, max	4.0	5.0	5.0	2.53
Na_2O, max	1.5	1.5	1.5	18.43
LOI	10.00	6.00	6.00	0.10

Table 4 TTLC and STLC data of CGIW

Contaminant	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
TTLC* result (mg/kg)	<1	0.01	276	24.94	1.99	11.48	0.66	72.56
TTLC Regulatory limit (mg/kg)	500	100	500	2,500	20	2,000	1,000	5,000
STLC ** result (mg/l)	0.05	<0.01	7.30	0.88	<0.01	0.74	0.07	8.75
STLC Regulatory limit (mg/l)	5	1	5	25	0.2	20	5	250

Remark: *TTLC: Total Threshold Limit Concentration, **STLC: Soluble Threshold limit Concentration

The total amount of SiO_2, Al_2O_3 and Fe_2O_3 in CGIW were 66.18%, which is similar to the composition of class C pozzolanic. However, it should be noted that the amount of Na_2O is greater than that classified by the ASTM standard for a pozzolanic material. Table 4 lists the toxicity characteristic data of CGIW [21]. This indicates that CGIW is classified as hazardous waste because the concentration leachate of chromium exceeds the STLC standard by Notification of Ministry of Industry.

2) *Effect of CGIW on compressive strength*

Compressive strength of concrete can be represented by the performance of a concrete cube subjected to ultimate load. Figure 4 shows the result on compressive strength development of concrete paving block of curing for 7, 14, 28, 42, and 56 days. The compressive strength of the cement cube spacimens containing CGIW tended to increase with curing time. It was observed that compressive strength decreased with higher levels of CGIW substitution for sand in the concrete. The compressive strength of a specimen containing 10%-20% CGIW with the curing period of 28 days was found to be 42.8 and 41.5 Mpa. Compared with the control mortar, the specimens with 10% and 20% sand replacement had lower compressive strengths of 5.56% and 7.70%, respectively. The reduction in compreessive strength could be due to either the high water absorption of CGIW or its high content of sodium oxide (Na_2O). The high amount of 18.43% Na_2O is likely to affect the alkali-silica reaction in the compressive strength development of concrete [25]. Figure 5 plots the compressive strength versus percentage of CGIW replacement of sand in mortars. Compressive strength testing shows that the replacement of up to 10% of fine aggregate had a negligible effect on the strength of concrete paving block. It was observed that the specimens with 20% sand replacement had the 28-day compressive strength higher than the TIS 827-2531 standard of 40 Mpa. It can be concluded that CGIW could be replaced for sand up to a level of 20% with negligible loss in compressive strength

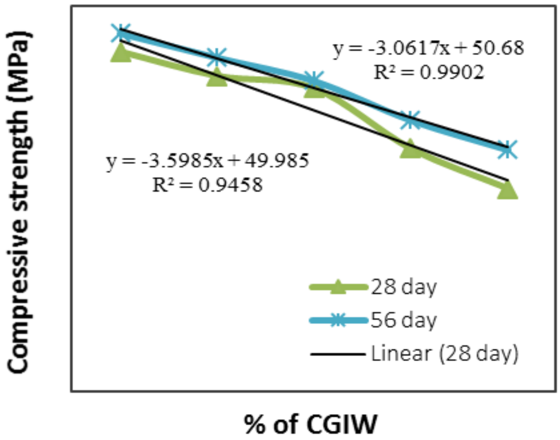

Figure 4 Compressive strength development curves for concrete mix

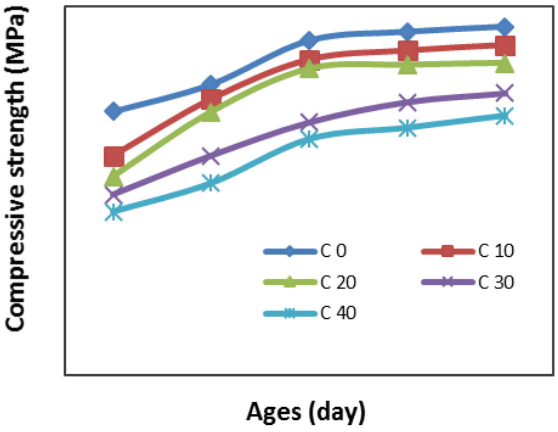

Figure 5 Compressive strength versus percentage of CGIW replacement of fine aggregate in mortars

3) *Effect of CGIW on density and water absorption*

The density of concrete paving block gradually decreased with increasing proportion of CGIW for all curing times. The density of concrete paving block containing 20% CGIW as sand replacement ranged between 2.18 and 2.20 g/cm^3, whereas the control mix was 2.26 - 2.28 g/cm^3 at for curing times of 7-56 days (Figure 6). The results emphasized that CGIW content could reduce the density of concrete paving block due to the replacement of lower density content in concrete. The reduction can reach up to 3.51-3.55% compared with the control mix.

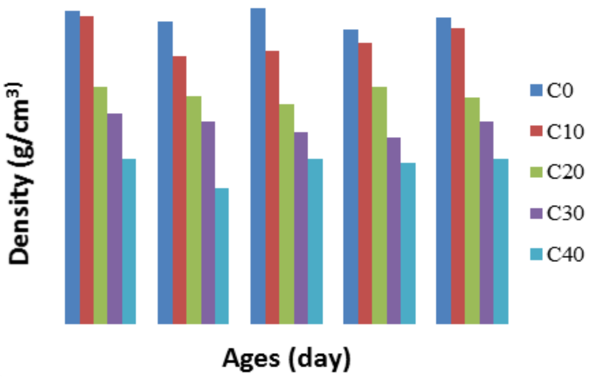

Figure 6 Density of concrete mix

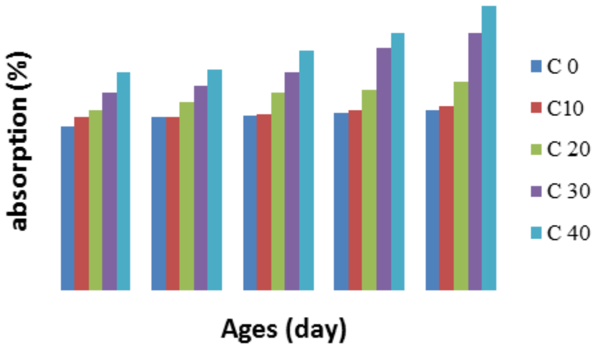

Figure 7 Water absorption of concrete mix

Figure 7 shows the test results of water absorption characteristics of concrete paving block. Water absorption rates tended to increase with increasing levels of CGIW replacement and curing time. According to Sengul et al. [16] an increase in water absorption will decrease the strength of concrete block paving. However, increasing the level of substitution of CGIW to 20% showed an insignificant effect on water absorption when compared with the control concrete paving block.

4) Effect of CIGW on concrete paving block properties

The optimum substitution level of fine aggregate with CGIW was found to be 20% by volume for production of concrete paving blocks. The concrete specimens with a ratio of cement: sand: rock of 1:1:2 and a ratio of sand: CGIW of 60:40 by volume were cast in metal moulds with a dimension of 110 mm x 65 mm x 250 mm. They were used for deter-mining the compressive strength, density and water absorption in a wet curing method at 28 days. The test results show that the compressive strength was 42.48 MPa, the density was 2.18 g/cm^3 and the water absorption was 4.62%. The results of material testing were found to be within the acceptable range of the interlocking concrete block paving standard set by Thailand Industrial Standards Institute.

5) The toxiccity characterization of concrete paving block containing CGIW

Table 5 presents TTLC and STLC results of the concrete paving block contained 20% CGIW replacement of sand. The leachate contained lower amounts of heavy metals than those regulated by the standard [21]. Therefore, the concrete paving block containing CGIW is not considered to be hazardous waste.

6) SEM micrograph testing

Figure 8 shows the production of hydra-tion and pozzolanic reaction of 20% CGIW replacement of sand. It can be seen that the interior surface texture of CGIW is not homogeneous, but the CGIW has attached calcium silicate hydrate (CSH). This product was obtained from the hydration and pozzolanic reaction.

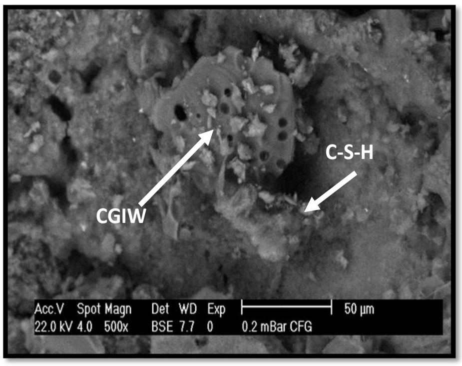

Figure 8 Product of hydration and pozzolanic reaction of CGIW

Table 5 TTLC and STLC results of concrete paving block contained 20% CIGW

Contaminant	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
TTLC* result (mg/kg)	5.10	<0.30	11.00	34.00	5.50	0.05	12.00	1.54
TTLC Regulatory limit (mg/kg)	500	100	500	2,500	20	2,000	1,000	5,000
STLC ** result (mg/l)	0.12	<0.01	0.67	2.36	<0.01	0.10	0.03	0.11
STLC Regulatory limit (mg/l)	5	1	5	25	0.2	20	5	250

Remark: *TTLC: Total Threshold Limit Concentration
**STLC: Soluble Threshold limit Concentration

Conclusions

Cellular glass insulation waste is shown to be a promising material for partially replacing typical fine aggregrate in concrete paving block production. Up to 20% by volume of CGIW was found to be optimal, causing no significant reduction in concrete strength. Testing of compressive strength of 41.50 MPa showed that concrete prepared with this optimal substitution level met the TIS 827-2531 standard. The density of concrete mixed with 20% CGIW sand replacement decreased by 4.39%, while water absorption increased by 11.37%. The waste extraction test of the concrete paving block containing CGIW showed no excessive leaching of heavy metals according to the standard for leachate. For the 110 mm x 65 mm x 250 mm concrete, the results of material testing were within the acceptable range for interlocking concrete paving block standard.

Acknowledgement

This work was supported financially by PTT Global Chemical Public Company Limited.

Reference

[1] S.D. Probert and S. Giani: Applied Energy. Vol. 2 (1976), p. 83-116.

[2] Md. Safiuddin, M.Z. Jumaat, M. A. Salam, M. S. Islam3 and R. Hashim (2010). Utilization of solid wastes in construction materials, International Journal of the Physical Sciences Vol. 5(13):1952-1963

[3] A. Pappu, M. Saxena, S.R. Asolekar (2007). Solid Wastes Generation in India and their Recycling Potential in Building Materials. Building and Environment, 42: 2311-2320.

[4] Aitcin P-C, Laplante P (1992). The Development of High Performance Concrete in North America. In: High Performance Concrete, E & FN Spon, London, UK, pp. 412-420.

[5] Fernández-Jiménez A, Palomo A, Criado M (2006). Alkali Activated Fly Ash Binders. A Comparative Study between Sodium and Potassium Activators. Mater. Constr., 56: 51-65.

[6] Malhotra SK, Tehri SP (1996). Development of Bricks from Granulated Blast Furnace Slag. Construction and Building Materials, 10: 191-193.

[7] Nasly MA, Yassin AAM (2009). Sustainable Housing Using an Innovative Interlocking Block Building System. In: Proceedings of the Fifth National Conference on Civil Engineering (AWAM ’09): Towards Sustainable Development, Kuala Lumpur, Malaysia, pp. 130-138.

[8] Bruder-Hubscher V, Lagrade F, Leroy MJ, Coughanowr C, Enguehard F (2001). Utilisation of Bottom Ash in Road Construction: Evaluation of the Environmental Impact. Waste Manage. Res., 19: 545-556.

[9] Rezende LR, Carvalho JC (2003). The Use of Quarry Waste in Pavement Construction. Resources, Conservation and Recycling, 39: 91-105.

[10] Pei-wei G, Xiao-lin L, Hui L, Xiaoyan L, Jie H (2007). Effects of the Fly Ash on the Properties of Environmentally Friendly Dam Concrete. Fuel, 86: 1208-1211.

[11] Malhotra VM (1987). Properties of Fresh and Hardened Concretes Incorporating Ground Granulated, Blast Furnace Slag. In: Supplementary Cementing Materials for Concrete. Canada: Minister of Supply and Services, pp. 291–336.

[12] Zhang MH, Malhotra VM (1996). High-Performance Concrete Incorporating Rice Husk Ash as a Supplementary Cementing Materials. ACI Mater. J., 93: 629-636.

[13] M. Limbachiya, M.S. Meddah, and S. Fotiadou: Construction and Building Materials. Vol. 28 (2012), p. 759-768.

[14] Information on http://www.business.scotland.gov.uk/bdotg/action/detail?itemId=108683 5198& site=202&type=RESOURCES

[15] A. Cheng, W.T. Lin, and R. Huang: Material and Design. Vol. 32 (2011), p.636-642

[16] O. Sengul, S. Azizi, F. Karaosmanoglu, and M.A. Tasdemir: Energy and Buildings.
Vol. 43 (2011), p. 671-676**.**

[17] Y. Ma, B. Zu, and M. Tan: Cement and Concrete Research. Vol. 35 (2005), p. 296-300.

[18] Standard specific for Portland cement. ASTM C150-07. American Society for Testing and material. ASTM Specification, Philadelphia; (2006).

[19] Standard Specification for Concrete Aggregates**.** ASTM C33**.** American Society for Testing and material. ASTM Specification, Philadelphia; (2006).

[20] Standard test method for sieve analysis of fine and coarse aggregates. ASTM C136. American Society for Testing and materials. ASTM Specification, Philadelphia; (2006).

[21] Ministry of Industry. Notification of Ministry Re: Industrial Waste Disposal B.E. 2548 (2005)

[22] Thailand industrial standard institute ministry of industry. TIS 827-2531 interlocking concrete paving block. Thailand industrial standards institute. (1988).

[23] Standard test method for density, absorbtion and voids in hardened concrete. ASTM C642. American Society for Testing and materials. ASTM Specification, Philadelphia; (2006).

[24] Standard specific for coal fly ash and raw or calcined natural Pozzolan for use in concrete. ASTM C618. American Society for Testing and materials. ASTM Specification, Philadelphia; (2006).

[25] M. Palacios and F. Puertas: Cement and Concrete Research. Vol. 35 (2005), p. 1358