Sustainable Concrete Utilizing Industrial By-Products – Research Review

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Abstract— Concrete is most widely used material around the globe construction purpose. Due to expanding vision of growth in construction sector the demand for concrete is increasing day by day. Portland cement is the main constituent of concrete, it is used as binder. Manufacturing of cement increases with increase in the demand for concrete. But the major issue with cement is its contribution to greenhouse gases. CO2 has major contribution in greenhouse gases and that leads to global warming and climate change. Almost 1000 kg of cement generates 900 kg of CO2. To meet the increasing demand of construction sector and achieve the reduction in emissions, alternative cementitious materials have to be utilized. This can be achieved by replacing cement with supplementary cementitious materials (SCM) generating from industry as by-product or available natural resources. Cement Kiln Dust (CKD), Lime stone powder (LSP), Electric arc furnace dust (EAFD), Heavy Oil fuel Ash (OA) and Silico Manganese slag (SiMn), are few industrial by-products that can be utilized in replacing cement from concrete and also benefitting industry with safe disposal of waste, both these leads to sustainable growth. This paper reviews the work of researchers in using SCM as partial replacement of cement for concrete.

Index Terms— Concrete, cement, greenhouse gas emissions, industrial by-products, oil ash, sustainability, SiMn slag

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1 INTRODUCTION

Portland cement concrete is most widely used building material throughout the world due to its strong, durable and fire resistance properties. It is extensively used in concrete construction of buildings, bridges, roadways, etc. Basic ingredients of concrete are cement, coarse and fine aggregates and water. Cement is a substance that is finely pulverized, dry and acts as binder to glue other materials together as a result of hydration after addition of water. The problem associated with Portland cement is the emission of carbon dioxide in its manufacturing process. Human activities are connected to greenhouse gas emissions that lead to global warming and climate change [1]. Cement industry is responsible for 5-7% of global CO_2 emissions [2]. Cement manufacture contributes greenhouse gases both directly through the production of carbon dioxide when calcium carbonate is burnt in the kilns, producing lime and carbon dioxide (CO_2) and also indirectly through the use of energy in the kiln, particularly if the energy is sourced from fossil fuels [3].

Though cement is the main source of strength in concrete, there is a need to decrease its quantity used by the construction industry in order to reduce the greenhouse gases and to conserve energy and mineral resources. In order to meet the requirements in construction growth and reduction in carbon foot print, cement needs to be replaced with supplementary cementitious materials (SCM) in concrete production. In recent years the focus of research has been on utilizing various industrial by-products as SCM's. Utilization of industrial by-products has two major advantages. One is reduction in carbon footprint and other been disposal of these wastes which may lead to environmental problems. This paper summarizes the work done by various researchers in utilizing industrial by-products as SCM's, materaisl selected are Cement Kiln Dust (CKD), Lime stone powder (LSP), Electric arc furnace dust (EAFD), Heavy Oil fuel Ash(OA) and Silico Manganese slag (SiMn) as supplementary materials in concrete.

2 LITERATURE REVIEW

2.1 Cement Kiln Dust (CKD)

CKD is an important by-product material of the cement manufacturing process. It is generated from burning of the raw materials in a rotary kiln to produce clinker. For each ton of clinker, a typical kiln generates around 6 to 7% ton of CKD [4]. It is a fine grained, solid and highly alkaline material. In general, CKD is a very heterogeneous mix both by chemistry and particulate size that are dependent on the raw materials, fuels, kiln pyro-processing type, overall equipment layout, and type of cement being manufactured [5]. It consists primarily of calcium carbonate and silicon dioxide that are similar to the cement kiln raw feed, but the amount of alkalis, chlorides and sulfates are considerably more in the CKD [6]. The major reasons for CKD to be removed from the process are, first, the quality of clinker must be maintained without increasing the level of alkalis, chlorides, and/or sulfates. The other reason is that, CKD must be removed to maintain stability of kiln, otherwise, volatiles at high concentrations in the kiln can cause severe material buildup and this leads to the production loss, blockage and even to shutting down of the kiln [7].

Al-Harthy et al [8] investigated the utilization of CKD as a cementitious material in concrete and mortar. The compressive strength of concrete with 0%, 5%, 10%, 15%, 20%, 25%, and 30% CKD was determined after 3, 7, and 28 days. Three different w/c ratios, 0.5, 0.6, and 0.7 by weight, were considered. The authors reported that the replacement of CKD does not increase the strength. They reported that incorporation

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CKD at low water-to-binder ratio to concrete mixtures does not show any negative effect. The mortars that were prepared with CKD had better absorption characteristics. However, above certain limits, the water absorption of the mortar increased which also lead to a decrease in the mortar strength.

Shoaib et al. [9] investigated the influence of CKD substitution on the mechanical properties of concrete. A total of 135 cubes and 135 cylinders were cast to study the effect of replacement of CKD on the mechanical behaviour of concrete. The concrete mixtures were prepared with 0%, 10%, 20%, 30%, and 40% CKD and tested after 1, 3, and 6 months. The mix proportion was cement - 1, sand - 1.9, gravel - 3.52, and w/c ratio – 0.5, the cement content used was 350 kg/m3. It was reported that the ultimate compressive as well as tensile strength decreased with an increase in the quantity of CKD.

Shah and Wang [10] investigated utilization of CKD and Class F fly ash (FA) in concrete in the process of developing green concrete. The effects of mechanical, chemical and thermal activations on strength and other properties of CKD-FA binders were investigated. To achieve this, two combinations were made, one with CKD and FA ratio of 50:50 and another with 35:65. The hydration of CKD-FA binder was activated with addition of NaOH as chemical activation, exposing to curing temperatures of 38° C and 50° C as thermal activation and different grinding regimes were used as mechanical activation. Results indicated that, when blend proportion and activation are properly applied, the binder made with CKD and fly ash will have satisfactory strength and performance, which provides potential applications for new cementitious product.

El-Sayed et al [11] have investigated the effect of CKD on the compressive strength of cement paste and on the corrosion behavior of embedded reinforcement. They reported that substitution of up to 5% by weight of cement by CKD produced no adverse effect on the cement paste strength or on the reinforcement passivity.

Maslehuddin et al [12] investigated CKD blended cement concrete specimens with 0%, 5%, 10%, and 15% CKD, replacing ASTM C 150 Type 1 and Type V cements. Mechanical properties and durability characteristics were assessed. Results indicated that compressive strength of concrete specimens decreased with the quantity of CKD and there was no significant difference in the compressive strength and drying shrinkage of 0 and 5% CKD cement concretes. The chloride permeability increased and the electrical resistivity decreased due to the incorporation of CKD. The performance of concrete with 5% CKD was almost similar to that of concrete without CKD. Therefore, it was suggested to limit the amount of CKD in concrete to 5% since the chloride permeability and electrical resistivity data indicated that the chances of reinforcement corrosion would increase with 10% and 15% CKD.

2.2 Limestone Powder (LSP)

LSP is obtained during the crushing of carbonate rocks, which are considered as the source of coarse aggregates. LSP could be utilized as a replacement of cement or as filler. The addition of limestone dust reduces the initial and final setting time, as well as porosity, whereas the free lime and combined water increase with increasing limestone content. Further, the addition of LSP enhances the rate of hydration as determined by the combined water contents [13]. Limestone filler affects the crystallization nucleus for the precipitation of calcium hydroxide. These effects produce an acceleration of the hydration of cement grains [14]. It could also be utilized as a viscosity enhancer in the production of self-consolidated concrete [15].

The addition of filler, like LSP, in concrete is considered as common practice in European countries, especially in France. Goals like technical, economic, and ecological fields can be achieved with the addition of LSP in cement. Technical benefits, like increase of early strength, control of bleeding in concrete with low cement content can be achieved [16]. From economical point of view, strength development with this type of cement is similar to that of Portland cement at low production and investment cost per ton of cement [16]. LSP develops the hydration rate of cement compounds and increases the strength at early ages. LSP does not possess pozzolanic properties, but it reacts with the alumina phase of cement to form a calcium monocarboaluminate hydrate with no significant changes on the strength of blended cement. LSP has good ability of packing cement granular skeleton and a large dispersion of cement grains [16].

Liu and Yan [17] studied the effect of LSP on microstructure of concrete using mercury intrusion porosimetry (MIP), backscattering scanning electron (BSE), scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques. The mix proportion design was based on the strength grade of concrete with cement content of 110, 130, 160 and 200 kg/m3 and to those mixes LSP of content 100 kg/m3 was added as filler. They reported that the compressive strength of concrete containing 100 kg/m3 limestone powder as addition can meet the strength requirement. Though LSP does not possess pozzolanic properties, its filling effect can make the paste matrix and the interfacial transition zone between matrix and aggregate denser, which improves the performance of concrete.

Heikal et al [13] investigated the effect of substitution of LSP in pozzolanic cement. They reported that the initial and final setting times as well as the total porosity reduce with the addition of LSP. However, the content of free lime and combined water increased with limestone content. Formation of carboaluminate due to LSP fills the pores between cement particles, and that speeds up the setting time of cement. Addition of LSP results in reduction in the diffusion coefficient of chloride ions, and increases the heat of hydration and compressive strength.

Dhir et al [18] investigated the performance of concrete produced by blending Portland cement and limestone, for mechanical and durability properties. They used 15, 25, 35 and 45% replacement of cement with LSP with a range of cement contents from 235 to 410 kg/m3, and free water content of 185 l/m3. They found that there were minor differences in the performance between Portland cement and 15% LSP blended cement concretes of the same cement and water-to-cement ratio. But, there was a decrease in the strength as the LSP content increased. However, the flexural strength and modulus of elasticity decreased with an increase in the LSP content. Permeation and durability properties at equal w/c ratio enhanced up to 25% LSP and poorer performance thereafter. For the latter, minor effects were generally noted up to 15% LSP, but a gradual depletion in performance with increasing LSP in concrete thereafter.

Moon et al [19] investigated the diffusion of chloride ions in concrete with and without LSP. In those mixes, cement was replaced with 0, 10, 20 and 30% of LSP content with a constant water-to-cementitious materials ratio of 0.45. They reported that the setting time of LSP was faster than that of control concrete. They observed that the compressive strength of all specimens decreased with increasing the content of LSP. Along with curing period, the trend of diffusion was found to increase. With the addition of 10 to 20% LSP, the diffusion coefficient was found to decrease.

Tahir and Khaled [20] investigated the effects of various proportions of LSP on fresh and hardened properties of concrete. The mixes were prepared by replacing fine aggregates partially. Several mixes were prepared with varying percentages of fine aggregates with LSP like 0, 5, 10, 15, 20, 25, and 30% with cement, water, fine aggregates, and coarse aggregates contents of 420, 210, 210, and 965 kg/m3, respectively. They found that the slump decreased as the dust content increased. The compressive and flexural strength increased up to 10% and decreased gradually later. Absorption was found to increase with an increase in LSP after a dosage of LSP 15%. Drying shrinkage increased up to 10%, and decreased as replacement level of LSP increases more than 10%.

Tsivilis et al [21] investigated the properties and behaviour of limestone cement concrete and mortar. The limestone cements were produced by grinding clinker, limestone and gypsum with varying percentages of limestone and clinker. The mixes were prepared with clinker replacing 0, 10, 15, 20, and 35% with limestone, and 0.5 water-to-cement ratio. For durability evaluation, the specimens were exposed to 3% NaCl solution. The compressive strength and workability of LSP concrete were similar to that of control concrete. The 20% LSP was found to be optimum for protection against reinforced corrosion. Sorptivity and chloride permeability were found to be similar to control concrete. The freezing thawing of LSP concrete was less when compared to control concrete. With the addition of limestone, the carbonation depth and total porosity of mortar decreases

2.3 Electric arc furnace dust (EAFD)

EAFD is generated as a by-product during the electric arc furnace steel making process. It is in the form of very fine powder forming major part of the smoke or fume from the furnace. The powder from the furnace is drawn through cooling pipes and collected in specially designed bag filters. This fine dust consists mostly of iron oxide and zinc oxide [22]. Other constituents include: oxides of calcium, magnesium, silicon, etc. It is reported that about 15 to 20 kg of EAFD is generated for each ton of steel produced [23]. During its production, the fine dust particles are released in atmosphere leading to a major pollution problem. As EAFD is considered hazardous by United States Environmental Protection Agency (US EPA), it must be stored in specialized landfill [22]. The world steel industry spends approximately $50 to $250 per ton to stabilize EAFD for landfill or for zinc recovery [22]. Due its high content of zinc, it can be used as secondary raw material for production of zinc or other products. The presence of zinc and pozzolanic materials will enhance the properties of concrete [23]. Initial studies conducted at King Fahd University of Petroleum and Minerals (KFUPM) have indicated that EAFD could be utilized as a retarder in concrete [22]. However, it is possible to utilize it as filler and/or a cementitious material. Addition of EAFD in concrete enhances the compressive and shearing strengths as well as resistance to abrasion and reduces chloride penetration [23].

Maslehuddin et al. [22] studied the mechanical properties and durability characteristics of ordinary Portland cement and blended cement (with silica fume and fly ash) concrete specimens with electric arc furnace dust (EAFD). Concrete specimens were prepared with and without EAFD. In the silica fume cement concrete, silica fume constituted 8% of the total cementitious material while fly ash cement concrete contained 30% fly ash. EAFD was added as 2% replacement of cement in the OPC concrete and 2% replacement of the total cementitious content in the blended cement concretes. Specimens were tested for compressive strength, drying shrinkage, initial and final setting time, slump retention, water absorption, chloride permeability, and reinforcement corrosion. Results of that investigation indicated that the setting time and slump retention tended to increase with the addition of EAFD. However, there was a gain in strength with the addition of EAFD. Further, the water absorption and chloride permeability were found to decrease and there was an increase in the corrosion resistance of concrete with EAFD when compared to OPC and blended concretes.

Alexandre et al [24] studied the waste behaviour of EAFD in Pozzolan-modified Portland cement paste (MP). To understand the residue effect and properties of cement paste in fresh and hardened states, setting time and heat of hydration were determined as well as mineralogical and micro structural characterization were evaluated. Results indicated that the EAFD retards the Portland cement's hydration reaction. At initial stages, the compressive strength was found to be less than control specimen but at advanced age significant gain was noted. The compressive strength with 5% EAFD was found to be similar to the reference MP cement paste at age of 28 days.

Xuefeng and Yuhong [25] assessed the physical properties and chemical composition of EAFD for its possible utilization in the cement production. Investigations were done and it was reported that the quality of cement produced with EAFD meets the requirements for Chinese specifications. It was also reported that the use of EAFD in cement is more economical than the use of iron ore.

2.4 Heavy oil fuel ash (OA)

OA is generated during the burning of oil in power generation plants. It is a very fine ash and most of it passes ASTM No. 200 sieve. OA consists of inorganic substances, such as SiO2, Fe2O3, and Al2O3 with 70 to 80% of unburned carbon [26]. It is presently disposed off as a waste material, posing environmental and storage problems. Initial screening tests conducted at KFUPM indicated that the pozzolanic activity of 5 to 20% OA cement mortar was much less than that of control concrete containing 100% cements [27]. The chemical characteristics of the OA generated at a power plant differ significantly from that of coal fly ash. The carbon content of OA is about

95% while that of coal fly ash generally ranges between 20% and 50%. Toxic heavy metals, such as vanadium (2.08% as V2O5) and nickel (0.37% as NiO) are also present in the OA. The high carbon content and presence of toxic heavy metals suggested that this fuel oil fly ash be considered as a hazardous respirable dust that demands careful handling during study [28].

Syed Khaja Najamuddin [29] replaced cement content with 5 and 10% of OA. The results indicated that the early strength of mixes was less than reference OPC concrete mixes whereas, the final strength was almost same as reference mix. The compressive strength decreased with increase in quantity of OA from 5% to 10% even it was also satisfactory. Due to the presence of heavy metals (e.g. vanadium and nickel) the OA blended specimens were carried out leachability of heavy metals test using US EPA Toxicity Characteristic Leaching Procedure (TCLP) method to determine the discharge of harmful substances from OA cement concrete specimens into the surroundings. It was depicted from the results that the concentration of vanadium, barium and chromium were below the allowable limits for toxicity characteristics. Therefore, the results indicate that all OA cement concrete specimens can be classified as non-hazardous.

Paya et al [30] investigated the chemical, physical and mineralogical characterization of oil-fuel ash and the behaviour of Portland cement mortars incorporating high amounts of oil-fuel ash (15, 30, 45 and 60%). Oil-fuel as was acquired from electric power plant in Spain. The results found that there is high absorption of water by oil-fuel ash particles which increases the amount of water required for workability. Due to presence of high amount of carbon the setting time of the paste was faster. The compressive strength of mortars was much lower than control mortar mix.

Abdullah [28] has investigated the stabilization of two eastern Saudi soils, namely non-plastic marl and sand utilizing CKD and OA. OA content of 0, 5, 10, and 15% was used with 0 and 5% cement content to stabilize non-plastic marl and sand. Several tests were performed to assess the engineering properties of soils with and without stabilizer. It was reported that OA was found to be a suitable chemical addition to treat non-plastic marl soil. OA content of 5% plus 5% cement was found to be adequate for the effective stabilization of non-plastic marl. It met the strength and durability requirements.

Most of the studies have addressed fly ash generated from burning coals. Literature on reuse and/or recycling of oil ash generated from combustion of heavy oil fuel is very scarce because of the limited use of this oil for power generation. Therefore, specific research programs should be initiated to identify possible uses for this type of oil ash.

2.5 Ground Granulated Silico Manganese Slag (SiMn slag)

It is a byproduct of ferro alloy production. It is generated during production of silico-manganese alloy (SiM alloy) by carbothermic reduction of raw materials submerged arc furnace [31]. The slag is separated from SiMn alloy during the casting process due to its density difference and then it is poured on slag bed and transported after one day for storage [32]. The annual production of slag is 1.2 to 1.4 tons of SiMn alloy produced [31]. In the year the year 2014 the production of SiMn alloy was approximately 12.8 million ton [33]. The main constituents of SiMn slag are SiO2, CaO, Al2O3, and MgO. The nature of SiMn slag is glassy [31]. The major difference found in SiMn slag was MnO content when compared to ground granulated blast furnace slag.

Nath et al [34] investigated the replacement of granulated blast furnace slag (GBFS) with granulated silico manganese slag (SiMn slag) in Portland slag cement. It was reported that the reactivity slows down with addition of SiMn slag in Portland slag cement in earlier stages but later it accelerates. GSS addition does not affect the structural reorganization and maintained similar bond nature. Portlandite, C-S-H, and C-A-H are major hydration products. Manganese oxide hydrate is formed in hydration of cement with SiMn slag. Earlier 7 days compressive strength of SiMn slag based cement was lower due to lower pozzolanic activity of SiMn slag at initial stage, gain of strength at later stages was much faster. As recommended by authors the SiMn slag can be used as potential raw material in replacement of GBFS in Portland slag cement.

Sanjay et al [31] used SiMn slag to develop alkali activated cement binder with different levels of reactivity using different milling devices such as ball mill, attrition mill and eccentric vibratory mill for. SiMn slag was acquired from FERROATLANTICA S.L. (Spain). SiMn slag milled in attrition mill has finest and narrow particle size. From the results it is evident that reactivity is also mill dependent as mechanical activation helps in increasing the reactivity of SiMn slag and formation of higher hydration products. C-S-H was the main hydration product with Mn in structure. Finally it was recommended that SiMn slag can be utilized as starting material for alkali activated cement binder.

Zhang et al [35] prepared a cementitious material by mixing 80wt% SiMn slag powder, 10wt% lime, and 10wt% anhydrite. SiMn slag was collected from ferromanganese silicon plant in Guangxi Province, China. Lime and anhydrite was used as activators. The slag was ground to specific area of 500 m2/kg using ball mill. The initial setting time was 5 minutes shorter than OPC standard whereas, compressive and flexural strength were much higher than OPC standard except the initial 3 days strength, it was less. IR spectra analysis found that stable substances are formed during hydration process. Hydration and strength development of SiMn slag cementitious material was mainly dependent on decomposition, migration and re-combination of Al3+ according to Si and Al NMR.

Frias et al [36] investigated the influence of SiMn slag on cement paste in different aggressive solutions. The slag was crushed to the fineness 456.9 m2/kg. Portland cement type I was used as reference paste and remaining blended pastes were prepared using SiMn slag with addition of 5% and 15% in Portland cement. Prismatic specimens were prepared and exposed to sodium sulphate (0.5 M), sodium chloride (0.5 M), artificial sea water and reference water. After 56 days of curing in aggressive solution it was found that cement paste samples with SiMn slag addition did not show any significant weight variation but the flexural strength was less compared to reference mix due to increase in porosity in slag blended pastes. SiMn slag blended mixes has shown greater porosity than OPC past and this was also in the case of fly ash, slag and silica fume cement paste. After analyzing the results it can be noted that the behaviour under aggressive conditions was good but finally it was specified that the long term exposures are required for additional durability information.

Frias et al [37] studied the behaviour of SiMn slag in cementitious matrix. The lag was collected from Spain and ground to fineness 456.9 m2/kg. Blended cements were prepared with 5% and 15% addition of SiMn slag. The SiMn slag was classified as acidic due to the value of chemical modulus lower than 1 (C/S < 1 are acidic and C/S > 1 basic, the C/S for SiMn slag was 0.59). The pozzolanic activity of SiMn slag was good at earlier stage and for comparison it was between the pozzolanic activity of fly ash and silica fume. From the results it is noted that there was no change in setting time and except earlier strength up to 7 days the strength at the end was almost equal to control mortars. Authors suggested that the using of SiMn slag as pozzolanic material in blended cements is viable.

4 CONCLUSION

Increasing demand for concrete and also reducing the consumption of cement in concrete to curb the carbon foot print can be achieved through utilization of SCM. The review presents the recent studies conducted on utilization of industrial by-products in cement and concrete. Industrial by-products like Cement Kiln Dust (CKD), Lime stone powder (LSP), Electric arc furnace dust (EAFD), Heavy Oil fuel Ash (OA) and Silico Manganese slag (SiMn) depicts that these materials can be utilized potentially in cement and concrete with better mechanical and durability properties. Few conclusions can be drawn from the above reviews.

- Various percentages of cement were replaced by CKD and mixtures were assessed for mechanical and durability properties. Researchers observed that that there is no adverse effect on concrete up to 5% replacement of cement with CKD, whereas, after 5% they found there is decrease in strength. The effect of mechanical, chemical and thermal activations on the combination of CKD and Class F fly ash (FA) in concrete was studied and it was reported that when blend proportion and activation are properly applied, the binder made with CKD and fly ash will have satisfactory strength.
- Initial and final setting times as well as the total porosity reduce with the addition of LSP in concrete. It enhances the rate of hydration in concrete and also increase of early strength, control of bleeding in concrete with low cement content can be achieved. Minor differences in the performance between Portland cement and 15% LSP blended cement concretes of the same cement and water-to-cement ratio. But, there was a decrease in the strength as the LSP content increased. Permeation and durability properties at equal w/c ratio enhanced up to 20-25% LSP and poorer performance thereafter.
- Initial studies suggest that EAFD retards the Portland cement's hydration reaction. The compressive strength at initial stage was found to be less than control specimen but at advanced age significant gain was noted. The quality of cement produced with EAFD meets the requirements for Chinese specifications. It is possible to utilize it as filler and/or a cementitious material. Addition of EAFD in concrete enhances the compressive and shearing strengths as well as resistance to abrasion and reduces chloride penetration.
- Initial screening tests indicated that the pozzolanic activity of 5 to 20% OA cement mortar was much less than that of control concrete containing 100% cements. The compressive strength of mixes decreased with increase in the content of OA. 5 to 10% of OA is optimum to be utilized as replacement of cement. The concentration of vanadium, barium and chromium were below the allowable limits for toxicity characteristics. Hence, OA cement concrete specimens can be classified as non-hazardous.
- Earlier 7 days compressive strength of granulated SiMn slag based cement was lower due to lower pozzolanic activity of SiMn slag at initial stage, gain of strength at later stages was much faster. Portlandite, C-S-H, and C-A-H are major hydration products with Mn in structure. The behaviour of granulated SiMn slag cement under aggressive conditions was good. Authors suggested that the using of SiMn slag as pozzolanic material in blended cements is possible.

Table1. Chemical Properties of CKD, LSP, EAFD, OA and granulated SiMn slag

Constituent	**CKD (%)**	**LSP (%)**	**EAFD (%)**	**OA (%)**	**SiMn Slag (%)**
SiO2	17.1	11.79	2.38	1.65	40.33
CaO	49.3	45.7	9.39	0.45	26.17
Al2O3	4.24	2.17	0.7	0.1	14.55
Fe2O3	2.89	0.68	33.6	0.47	0.75
SO3	3.56	1.04	2.6	-	0.12
MgO	1.14	1.8	2.3	0.48	5.74
MnO	-	-	1.8	-	9.9
K2O	2.18	0.84	1.7	0.03	2.2
ZnO	-	-	10	-	-
Sulphur	-	-	-	9.6	-
V2O5	-	-	-	2.65	-

REFERENCES

[1] X. F. Zhang, S. Y. Zhang, Z. Y. Hu, G. Yu, C. H. Pei and R. N. Sa, "Identification of connection units with high GHG emissions for low-carbon product structure design," Journal of Cleaner Production, vol. 27, p. 118–125, May 2012.

[2] E. Benhelal, G. Zahedi, E. Shamsaei and A. Bahadori, "Global strategies and potentials to curb CO2 emissions in cement industry," Journal of Cleaner Production, vol. 51, p. 142–161, 15 July 2013.

[3] "U.S.Energy Information Administration," Emission of Greenhouse Gases Report, U.S. Department of Energy, December 2009.

[4] A. O. Al-Refeai and A. A. Al Karni, "Experimental Study on the Utilization of Cement Kiln Dust for Ground Modification," Engineering Science, vol. 11, pp. 217-232, 1999.

[5] M. Maslehuddin, O. S.B. Al-Amoudi, M. Shameem, M. K. Rehman and M. Ibrahim, "Usage of Cement Kiln Dust in Cement Products – Research Review," Construction and Building Materials, vol. 22, no. 12, pp. 2369-2375, 2008.

[6] "Beneficial Uses of Cement Kiln Dust," IEEE-IAS Cement Industry Committee, Cement Industry Technical Conf., Miami, FL, pp. 19-22, May 2008.

[7] O. S. Khanna, "Characterization and Utilization of Cement Kiln Dusts (CKDs) as Partial Replacements of Portland Cement," PhD Dissertation, Department of Civil Engineering, University of Toronto, 2009.

[8] A. S. Al-Harthy, R. Taha and F. Al-Maamary, "Effect of Cement Kiln Dust (CKD) on Mortar and Concrete Mixtures," Construction and Building Materials, vol. 17, no. 5, pp. 353-360, 2003.

[9] M. M. Shoaib, M. M. Balaha and A. G. Abdel-Rahman, "Influence of Cement Kiln Dust Substitution on the Mechanical Properties of Concrete," Cement and Concrete Research, vol. 30, no. 3, pp. 371-377, 200.

[10] S. P. Shah and K. Wang, "Development of "Green" Cement for Sustainable Concrete Using Cement Kiln Dust and Fly Ash," nternational Workshop on Sustainable Development and Concrete Technology, Beijing, China, 2004.

[11] H. A. El-Sayed, N. A. Gaber, S. Hanafi and M. A. Mhran, "Reutilization of By-Pass Kiln Dust in Cement Manufacture," International Conference on Blended Cement in Construction, Sheffield, UK, 1991.

[12] M. Maslehuddin, O. S. B Al-Amoudi, M. K. Rahman, M. R. Ali and M. S. Barry, "Properties of Cement Kiln Dust Concrete," Construction and Building Materials, vol. 23, no. 6, p. 2357–2361, 2009.

[13] M. Heikal, H. El-Didamony and M. S. Morsy, "Limestone-filled pozzolanic cement," Cement and Concrete Research, vol. 30, no. 11, pp. 1827-1834, 200.

[14] T. R. Naik, F. Canpolat and Y. M. Chun, "Limestone Powder Use in Cement and Concrete," Report, Center for By-Products Utilization, The University of Wisconsin–Milwaukee, 2003.

[15] F. Burak, "Utilization of High Volumes of Limestone Quarry Wastes in Concrete Industry (Self-compacting concrete case)," Resources, Conservation and Recycling, vol. 15, no. 4, p. 770–791, 2007.

[16] V. Bonavetti, H. Donza, G. Mene´ndez, O. Cabrera and E. F. Irassar, "Limestone Filler Cement in Low W/C Concrete: A Rational Use of Energy," Cement and Concrete Research, vol. 33, pp. 865-871, 2003.

[17] S. Liu and P. Yan, "Effect of Limestone Powder on Microstructure of Concrete," Journal of Wuhan University of Technology, vol. 25, no. 2, pp. 328-331, 2010.

[18] R. K. Dhir, M. C. Limbachiya, M. J. McCarthy and A. Chaipanich, "Evaluation of Portland Limestone Cements for Use in Concrete Construction," Materials and Structures, vol. 40, no. 5, pp. 459-473, 2007.

[19] H. Y. Moon, H. S. Jung and J. P. Kim, "Diffusion of Chloride Ions in Limestone Powder Concrete," Journal of the Korea Concrete Institute, vol. 16, no. 6, pp. 859-865, 2004.

[20] C. Tahir and M. Khaled, "Effects of Crushed Stone Dust on Some Properties of Concrete," Cement and Concrete Research, vol. 26, no. 7, pp. 1121-1130, 1996.

[21] S. Tsivilisa, G. Batis, E. Chaniotakis, Gr. Grigoriadis and D. Theodossis, "Properties and Behavior of Limestone Cement Concrete and Mortar," Cement and Concrete Research, vol. 30, no. 10, pp. 1679-1683, 2000.

[22] M. Maslehuddin, F. R. Awan, M. Shameem, M. Ibrahim and M. R. Ali, "Effect of Electric Arc Furnace Dust on the Properties of OPC and Blended Cement Concretes," Construction and Building Materials, vol. 25, no. 1, p. 308–312, 2011.

[23] C. A. C. de Souza, A. T. Machado, L. R. P. A. Lima and R. J. C. Cardoso, "Stabilization of Electric-Arc Furnace Dust in Concrete," Materials Research, vol. 13, no. 4, pp. 513-519, 2010.

[24] S. Alexandre, A. B. Masuero and A. C. F. Vilela, "Investigations on the Use of Electric Arc Furnace Dust (EAFD) in Pozzolan-Modified Portland Cement I (MP) Pastes," Cement and Concrete Research, vol. 36, no. 10, pp. 1833-1841, 2006.

[25] X. Xuefeng and T. Yuhong, "Application of Electric Arc Furnace Dust in Cement Production," Iron Steel (Peking), vol. 33, no. 6, pp. 61-64, 1998.

[26] W. T. Kwon, D. H. Kim and Y. P. Kim, "Characterization of Heavy Oil Fly Ash Generated from a Power Plant," Advances in Technology of Materials and Materials Processing, vol. 6, no. 2, pp. 260-263, 2004.

[27] "Final Report," Alternative Cementitious Materials," Center for Engineering Research, King Fahd University of Petroleum and Minerals, June 2010.

[28] G. M. S. Abdullah, "Stabilization of Eastern Saudi Soils Using Heavy Fuel Oil Fly Ash and Cement Kiln Dust," MS Thesis, Civil Engineering Department, King Fahd University of Petroleum and Minerals, 2009.

[29] S.K. Najamuddin, "PRODUCTION OF MEDIUM TO LOW STRENGTH CONCRETE UTILIZING INDIGENOUS WASTE PRODUCTS," M.S. Thesis, King Fahd University of Petroleum and Minerals, 2011.

[30] J. Paya, M.V. Borrachero, J. Monzó and M. Bonilla, "Properties of Portland cement mortars incorporating high amounts of oil-fuel ashes," Waste Management, vol. 19, no. 1, pp. 1-7, 1999.

[31] Sanjay Kumar, P. García-Triñanes, Amândio Teixeira-Pinto and M. Bao, "Development of alkali activated cement from mechanically activated silico-manganese (SiMn) slag," Cement & Concrete Composites, vol. 40, pp. 7-13, 2013.

[32] Moisés Frías, M. Isabel Sánchez de Rojas and Cristina Rodríguez, "The influence of SiMn slag on chemical resistance of blended cement pastes," Construction and Building Materials, vol. 23, p. 1472–1475, 2009.

[33] "Overview of the Global Manganese Industry," IMnI Annual Conference , Aloys d'Harambure , International Manganese Institute, Shanghai, June 18, 2015 .

[34] S.K. Nath and Sanjay Kumar, "Evaluation of the suitability of ground granulated silico-manganese slag in Portland slag cement," Construction and Building Materials, vol. 125, pp. 127-134, 2016.

[35] Xu-fang Zhang, Wen Ni, Jun-yu Wu and Li-ping Zhu, "Hydration mechanism of a cementitious material prepared with Si-Mn slag," International Journal of Minerals, Metallurgy and Materials, vol. 18, no. 2, p. 234, April 2011.

[36] Moisés Frías, M. Isabel Sánchez de Rojas and Cristina Rodríguez, "The influence of SiMn slag on chemical resistance of blended cement pastes," Construction and Building Materials, vol. 23, p. 1472–1475, 2009.

[37] M. Frias, M.I.S de Rojas, J. Santamarı´a and C. Rodrı´guez, "Recycling of silicomanganese slag as pozzolanic material in Portland cements: Basic and engineering properties," Cement and Concrete Research, vol. 36, p. 487 – 491, 2006.