JPIChE 49 (1) 2021: 33-39

Journal of Pakistan Institute of Chemical Engineers

journal homepage: www.piche.org.pk/journal

A Technical Feasibility Study and Environmental Impacts of Green Cement Production from Recycled Fly Ash in Pakistan

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Submitted: 12/01/2021, Accepted: 13/04/2021, Online: 14/04/2021

Abstract

In contrast to traditional Portland cement, green cement is an environmental friendly and sustainable option that offers a reduction in greenhouse gas (especially carbon dioxide) emissions. Green cement comprises of a higher component of alumino-silicates, in turn, which has increased the demand for renewable energy and recycling of waste materials. This study presents a technical discussion on the possibilities for producing green cement in Pakistan. Although a variety of alumino-silicate-based materials like rice husk, sugar cane and furnace slag are studied, fly ash is a raw material of choice for green cement owing to its availability, lower costs, and eases in conversion, energy savings and low green houses emissions. The study also provide estimates of fly ash can replace 80-100% of the limestone used for the traditional Portland cement in Pakistan, however, requiring a sodium-based activator. The study concludes with an overview of the site selection and identifies a suitable area in the Sindh region of Pakistan.

Keywords: Green Cement, Limestone, Particle Size, Fly Ash, Clinker, Loss on Ignition (LOI).

1. Introduction:

In light of the steady global drive towards environmental sustainability, emerging initiatives and decisions seek to implement more comprehensive measures towards the need to recycle industrial wastes, mitigate anthropogenic emissions, and reduce energy consumption. Concrete is the world's most used construction material, with global estimates of 3.8 billion m3 per year which is approximately 9 billion tons [1, 2]. Its production is one of the most ecologically-taxing industrial practices, facing increased restrictions and harsher growing regulatory codes. In addition to being energy and emission intensive, the acquisition of concrete's major components (cement and aggregate) contributes to the heavy depletion of natural resources. The carbon emissions from cement manufacturing industries account approximately 5% of the total global anthropogenic carbon dioxide [3, 4]. It is estimated that a kg of Cement generates approximately 0.85 tons of CO2. Therefore, to replace the natural raw material substance with the waste material which has equally sustainable properties and eco-friendly more it's economical. In present study to promote the materials which are sustainable and environmentally friendly [5, 6]. Therefore, individual constituents can be substituted or modified with materials that exhibit similar or enhanced properties, to form varying composite materials, as long as the required concrete properties are maintained. Such constituent substitution can either result in high performance concrete variants aimed at specialist markets, or

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provide a variation of concrete which appeals to developing nations, as it may not provide enhanced performance but it might meet basic material property requirements at a reduced cost. The material which replace the limestone and clay in terms of properties and economics are marble sludge powder, quarry rocks, coffee husk, rice husks, Sugar cane bagasse, silica fume, crushed concrete and fly ashes which are some of the materials used for making green concrete, a sustainable for construction. Limestone used as a major component in making the cement. Limestone properties that are used in these calculations are from the research paper given in reference [7-10]. An example of high performance concrete is the fly-ash concrete used for dam construction and river tunnels, [11] who exhibited a reduction in permeability, improved long- term strength and chloride resistance. An example of low-cost concrete for developing nations is the use of rice husk cement in Cuban low-cost housing panels researched by Swamy (1986), which has lasted over 18 years [12-14].

This research on the allocation and installation of the green cement plant weather it is possible or not in Pakistan. For this purpose this study has been done to find the ratio of the waste material to the natural raw material used (limestone). Focus on the environment friendly and to modify some new techniques to flourish in congenital environment.

2. Materials And Method:

2.1 Green Cement:

The natural color of cement is gray, varying between lighter and darker shades. What is green means? Obviously, “green” does not refer or means to the color of the cement. It refers to the philosophy that lies behind the new design concepts of cement plants which is green in nature. A green cement plant is the plant that is designed to conserve all the natural resources which helps to release of the greenhouse gases (GHG) to the atmosphere [15-17].

2.2 Fly Ash:

Fly ash or flue ash is known as pulverized fuel ash. Fly ash is a product of coal combustion that is consists of the particulates that are driven out of coal- fired boilers together with the flue gases. Ash that falls to the bottom of the boiler's combustion chamber is called bottom ash. Fly ash used as a waste recycled material for the making of green cement as it has many benefits like properties of fly ash which contains high amount of silica oxide and other materials that replace clay completely and abundant amount of limestone replaced. In present study the amount of fly ash used is calculated [18, 19]. Fly ash can replace 80 to 100 % of the cement in making concrete but for this purpose activator is used. Some researcher investigated that fly ash could be replaced from limestone and clay, 30% fly ash in place of limestone and clay like materials gave better results [20, 21]. Benefits of using Fly ash: Makes use of industrial waste. Requires less energy as fly ash is already burned, limited carbon dioxide emissions in the environment, beneficial for contractors, making cement from fly ash is long lasting, Production of multi-component cements enables not only fuel energy savings (by 30-40%) but also increased volumes of concrete production and use of fly ash allows optimization of the main characteristics of cement clinker and reduction of CO2 emissions due to a greater cement/clinker ratio [22, 23]. In the future, emitting CO2 may attract penalties. Therefore clinker making process will be increasingly replaced by materials like fly ash, slag, limestone powder, natural pozzolans, etc. The type of additive that used for making composite cement will depend mainly on its local availability. From this point of view, fly ash suggests itself as the most convenient additive for use in cement plants [24, 25].

2.3 Experimental Setup:

The manufacturing process of green cement plant is the same as the usual cement manufacturing process. In present study use the dry process for manufacturing the green cement because dry process uses less amount of water as compare to wet process and less economical process. In dry process, first step is the mixing of raw material as possible by reducing the size of the material because solid mixing is difficult as shown in fig. 1. Then the

material is to be burned in the kiln and pre-heater. Clinker is made in the cooler after sudden cooling of the output material of the kiln. Grinding is to be done of clinker and gypsum to increase the settling time of the Cement. Last step is the storage of Cement Storage, packaging and dispatch [26-28].

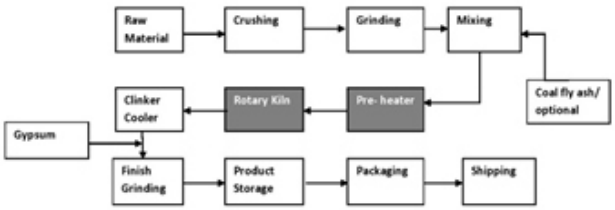

Figure 1: PFD of cement plant

There is no proper setup for Green Cement in Pakistan. In fact, there is no plant in world that works on Green Cement at large scale production. In present study the availability of raw material is the big challenge to installing this green cement plant. Mostly factors that will directly influenced on the plant feasibility technique.

2.4 Plant Location & Installations:

In Pakistan there is excessive availability of the fly ash, in other words, fly ash cannot be utilized for industrial process, known as a waste material and can harm the environment and land. So, the present research purpose is to install the green cement plant in Pakistan.

In Pakistan there are many coal based power plants which produces large amount of fly ash and also there are many coal based power plant in progress, this plants is feasible in Pakistan due to the availability of raw material in large amounts. Pakistan is that place where both raw material that consider in our research limestone and fly ash available near the Jamshoro in Sindh province. So, Sindh is ideal place for installing a plant and it is valuable for both investor and locally located person. Green cement plant is first ever installation that will not damage the environment and its revenue generation capacity is high as compared to grey cement because of low emission of harmful gases and waste of coal fired plant used as a feedstock. Moreover, the grey cements facing the challenges to overcome the resources of energy and CO2 emissions. However, in green cement there is no excessive need for crushing and grinding.

3. Comparison of Results & Discussions:

To investigate the amount initially for installing a 1000 MTPD of clinker for green cement on large scale according to Pakistan standard based cement given in below table 1. According to present calculations these data is necessary to proceed and on this basis calculation is required from limestone, fly ash and coal ash which is generated during the combustion process in kiln and pre-heater.

Table 1: Final composition of cement required according to Pakistan standards (PS-232) [29]

Compound (Tons/day)	%age	Amount
C_3S	53.8	538
C_2S	20.19	201.9
C_3A	6.4	64
C_4AF	12.04	120.4
LOI (Loss on Ignition)	1.92	19.2
IR (Insoluble Residue)	0.4	4
Alkali eq.	0.6	6
MgO	2.84	28.4
Cl_2	0.01	0.1
Free lime	1.8	18
Total	100	1000

For the final calculation of cement composition the amount of raw material needed is, for this purpose used the data of local fly ash produced by Jamshoro power generation plant. So the composition of fly ash used is given in table 2,

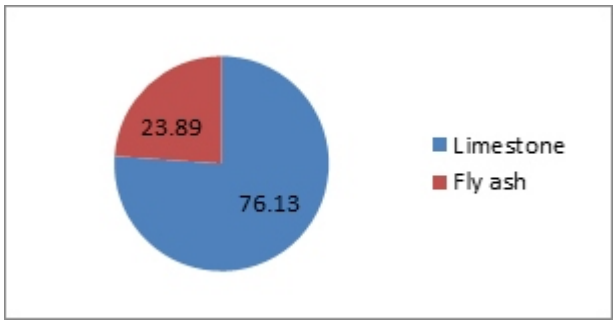

Figure 2 (A): Feed composition

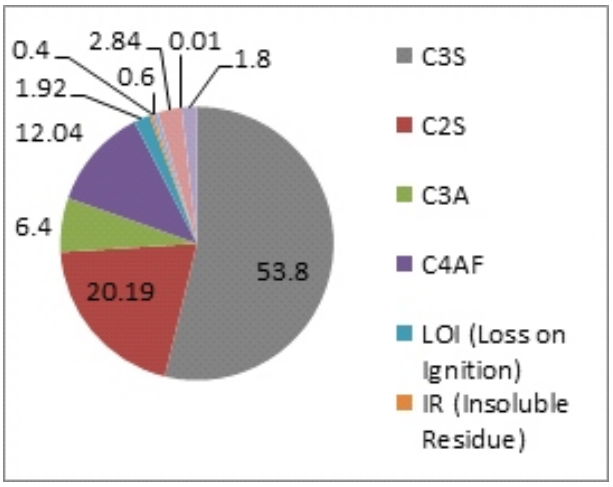

Figure 2(B): Final composition of cement

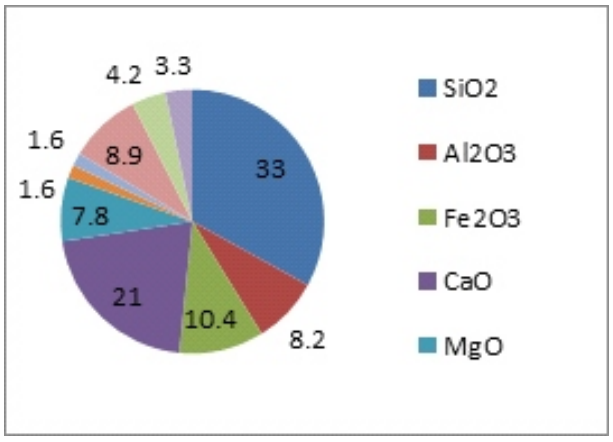

Figure 2 (C): Fly ash composition

In fig.2 (A) explains the amount of feed stock that require for the green cement production indicates almost 24 % fly ash obtained from power plant used as a source. Fig.2 (B) indicates the presence of components in green cement having large amount of C_3S which is important in cement binding and finishing. Fig.2 (C) indicates the composition of ash having large abundance of SiO_2 which is 33% important for replacement of direct use of sand already exists in fly ash, no cost for initial purchasing and processing.

Table 2: Fly ash composition of Jamshoro power generation plant [30]

Compound	%age	Amount (Tons/day)
SiO_2	33	118.8
Al_2O_3	8.2	29.52
Fe_2O_3	10.4	37.44
CaO	21	75.6
MgO	7.8	28.08
$Na_2O + K_2O$	1.6	5.76
TiO_2	1.6	5.76
SO_3	8.9	32.04
LOI (Loss on Ignition)	4.2	15.12
Undetermined	3.3	11.88
Total	100	360

Initially investigate the 1000 MTPD, the amount of limestone and the fly ash needed as present work want to replace major part of limestone and completely replaced clay with fly ash. Results show that fly ash has the property to replace completely with clay. As clay has major part is silica which is abundantly available in fly ash as shows in table 2.

Table 3: Consumption of raw material in grey cement production in tons [31]

Compound	Per tons clinker	Per tons cement	Per year per Mt clinker
Limestone, clay,	1.57	1.27	1568000
shale			
Gypsum anhydrite	--	0.05	61000
Mineral additives	--	0.14	172000

In table 3 indicates the large amount of limestone need to produce green cement which is quite expensive to handle as compared to fly ash having their own clay and limestone. The limestone calcium oxide is the major component used for the green cement production and it is easily available in fly ash. The amount percentage of fly ash that is used to replace the limestone is 24% approximately but it may increase according to requirement as suggested in present study that it is just an initial step towards creating a plant on based of recycled fly ash. There are also more recycled material that

can be replaces limestone and clay just like a rice husks but the feasibility of that material is not good and availability of rice husks is low. Rice husks making cement has lowest amount of carbon dioxide emission.

3.1 Effect of Particle Size:

In present study the particle size has marginal effect on the production of green cement. As increase in particle size the effect of cost for size reduction and quality decline to the standards. On the contrary, small particle size has large surface area and yield ratio is comparatively better due to efficient increased the activity than large particle size. In present stud capacity can be according to desired requirement. The amount of fly ash replace from 30 % fly ash to 100% but for this case sodium based activator added instead of limestone and clinker. But present study shows that easily replace limestone up to 30 to 40%.

Table 4: Raw material composition of clinker for grey cement [27]

Compound	Sources	% mass
Lime	Limestone, shell and chalk	60-67
Silica	Sand, fly ash	17-25
Alumina	Clay, shale, fly ash	2-5
Iron oxide	Iron ore	0-3
Total		100
Compound	Sources	% mass

Table 5: Feed amount [30, 32]

Compound (Tons/day)	Amount	%age
Limestone	1146.49	76.13
Fly ash	360	23.89
Total	1506.49	100

Table 4 and 5 shows the importance of feed composition require for the production of grey and green cement. Fly ash as a feed in green cement almost 24 % and no further amount of silica, alumina and iron oxide required because fly ash consist of all kind of constitutes which is separately require for processing. If the consideration is made on the basis of 1000 MTPD then the amount of fly ash require is given in table 5.

4.1 Energy/Water Consumption:

Energy consumption is more in case of large particle size both crushing and grinding is required to convert the material into desired size also in fig. 1 rotary kiln and pre-heater. In case of wet process large amount of water is converted to moisture when shifted to the cooler and heater make high loss of weight with flue gases. This can be improved by utilizing some kind of pre-heater before going to process. Energy consumption control by using the temperature of flue gases into steam generator, continuous removal of blow down which are particulate matters slightly affect the efficiency of process, and implement the pinch/recycling techniques. Availability of water depend on the location and process selection, utility section heavily depend on the water, which create the impurities and corrosion.

3.2 Emission to Air:

Comparatively the way of manufacturing the green cement has low emission than gray cement. Table 6 shows the amount of particulate matters released during the process, SO2 amount is very high which has environmental restrictions in case of grey cement but in green cement manufacturing the SO2 amount present in fly ash is short given in table 4, which already being processed from power generation plant.

Table 6: mission ranges from cement kiln [33]

Pollutant	mg/Nm3	Per tons clinker	tons Per year
NOX	145-2040	0.33-4.67	334-4670
SO2	Up to 4837	Up to 11.12	Up to 11125
DUST	0.27-2273	0.00062-0,5221	0.62-522
			460-11500
CO	200-2000	0.46-4.6	1.5456million
CO_2	--	Approx.672g/tons	2,176-267
TOC*/VOC*	1-60	0.0023-0.138	0,21-23.0
HF	0.009-1,0	0.021-2.3g/t	0.046-46
HCL	0.02-20,0	0.046-46g/t	0.0000276-
			0.627g/year

*Total organic compound/ vaporized organic compound

4. Conclusions:

This research concludes that it is easy to replace limestone with fly ash with some amount but in present case replaced it for 24% approximately

which is the initial step. Need to find the more ways which can be eco-friendly, economical and most probably have to use the local waste material as recycled material and use of local industrial waste. This research is completely base on Pakistan and to create a plant in Pakistan on based of fly ash. Most countries like India and china worked on this but on small scale because the amount of both raw material not available in same place easily. The advantage to install green plant in Pakistan, the fly ash will be available from Jamshoro power plant. Approximately 5 km from west of Jamshoro, there are huge resources of limestone available. Further required data will be collected from the Geological Survey of Pakistan and Sindh Bureau of Statistics Planning & Development Department.

Acknowledgment:

Authors are thankful to NFC Institute of Engineering & Technology, Faisalabad for providing the technical assistance in writing this research article.

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