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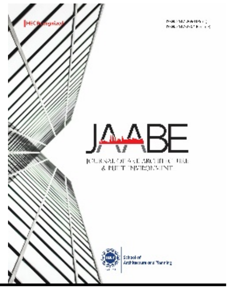

Title: **Fly Ash Cement Block as a Sustainable Product versus the Clay Brick: A Case Study Conducted in Sargodha, Pakistan**

Author (s): Nazia Iftakhar, Rehman Adrees, Omer Shujat Bhatti

Affiliation (s): Allama Iqbal Open University, Islamabad, Pakistan

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Fly Ash Cement Block as a Sustainable Product versus the Clay Brick: A Case Study Conducted in Sargodha, Pakistan

Nazia Iftakhar*, Rehman Adrees, and Omer Shujat Bhatti

Department of Environmental Design, Health & Nutritional Sciences, Allama Iqbal Open University, Islamabad, Pakistan

Abstract

Due to increased anthropogenic activities resulting in enhanced urbanization and industrialization, natural environment has sustained extensive damage and remains in a state of rapid degradation. Hence, it is essential to transform the pollutants and waste products produced by anthropogenic activities into environment friendly products, so as to ensure the reduction of their negative impact. One such product generated from the burning of fossil fuels and kilns is fly ash. It can cause environmental pollution if not managed appropriately. It can be used in combination with cement to develop cement blocks needed for building structures. The current research aimed to develop the said potential of fly ash produced by the Sargodha city brick kilns and transform it into a sustainable green product, namely fly ash cement block. For this purpose, waste was collected to produce cement blocks with four different compositions, further tested for their compressive strength and water absorption. It was determined that a cement block containing 10% fixed cement proportion with 60-70% fly ash delivered a competitive product against local bricks which are neither green nor sustainable. Moreover, the texture, shape, and size of the block were very similar to clay bricks. Also, the cost of fly ash block was 20-25% cheaper than local bricks. The samples were further taken to the local market of Sargodha city to evaluate their economic value addition. It was determined that more than 80% of retailers were willing to use fly ash cement block since it has the capacity to compete with the locally available non-green products, if produced commercially on a large scale. Whereas, 60% of consumers were found to have limited knowledge about the material.

Keywords: anthropogenic activities, cement blocks, clay bricks, environmental pollution, fly ash, sustainable material

* Corresponding Author: nazia.iftakhar@aiou.edu.pk

Introduction

Built environment acts as a shelter for human beings. Nevertheless, the built environment incurs a significant cost that directly impacts one of the most vulnerable resources available, namely the environment and natural resources. This impact occurs as the built environment relies on the extraction, processing, transportation, storage, deployment, and eventual utilization of resources derived from the environment and nature, all of which follow the life cycle of the product or material. (Andersen et al., 2020). During all of these processes, the environment is damaged through extraction, pollution, contamination, and the generated waste (Ukaogo et al., 2020). Hence, the construction industry imposes a substantial environmental cost for providing shelter and improving the quality of life for its inhabitants. Conversely, energy resources for HVAC plays a pivotal role as the most essential resource for enabling and sustaining the operation of the built environment.

The energy supplied to buildings during and after their construction comes from non-renewable sources which leads to global warming and climate change (Ghafoor et al., 2020; Mahar et al., 2019; Abdul & Yu, 2020). The increase in energy demand has put an enormous pressure on the world energy systems to generate ample energy to fulfill the needs of human population all around the globe (Cengizler et al., 2012). Fossil fuels are a leading source of energy and fulfill the global energy requirements more than any other resource. The production of fossil fuels is marred by poor energy management and a higher waste production rate. Furthermore, Green House Gases (GHG) including Carbon dioxide (CO_2), Carbon monoxide (CO), Sulphur oxides (SO_x), and Nitrogen oxides (NO_x), are produced as a result of the burning of fossil fuels. These gases cause rapid environmental degradation and global warming due to their high concentration in the atmosphere (Kayali, 2005).

The construction industry is experiencing a significant boom and is estimated to grow by 35% as compared to the previous decade. The global construction market is expected to expand from US$4.5 trillion to US$15.2 trillion, with China, India, US, and Indonesia accounting for 58.3% of the forecasted growth. Construction industry was forecasted to grow by 6.6% in 2021 and by 42% until 2030 (Ellis, 2021). In Pakistan, the construction industry can be considered as the backbone of national development

(Akhund, 2019) since it is the largest sector which consumes about 80% of the national development budget.

Concrete is the most commonly used composite material. It can be used extensively in a variety of structures because of its great strength and due to the fact that it can be transformed into any shape or form (Maqsoom et al., 2017). Despite being regarded as one of the most favorable combinations, in the form of Reinforced Cement Concrete (RCC) and Plain Cement Concrete (PCC), keeping in view the diverse scale and nature of construction works (Caldas et al., 2021). However, it is energy intensive and CO_2 emission during its manufacturing, utilization, and processing makes it one of the most unsustainable material choices for the environment. In order to minimize these effects, fly ash can be used as a substitute material for construction purposes (Pushpraj et al., 2015). Fly ash is a waste material generated from the energy generation units of construction and allied industries, including brick kilns and burning of fossil fuels (Abbas et al., 2017). Its improper usage and spilling into water and open lands cause environmental pollution in various forms, including ground water contamination (Chaulia et al., 2009), ecological destruction (Iftikhar et al., 2020), and serious health concerns.

This waste by-product must be effectively disposed to eliminate air, soil, surface, and ground water pollution (Xu & Shi, 2018). Fly ash is used extensively in multiple compositions and results in their good quality, strength, and durability due to its strong pozzolanic properties (Ghazali et al., 2019; Gadling & Varma, 2016). Indeed, it may lead to a composition which may not only save the rapidly deteriorating environment but can also lead to enhanced economic benefits. It may replace cement by a mass of around 30% in PCC composition (Turuallo & Mallisa, 2018). It may also act as a strengthening factor by combining with cement into the overall concrete mix composition.

Pakistan is the third largest country in South Asia in terms of clay bricks production, producing around 45 billion clay bricks per year (Ahmad et al., 2022). In the Punjab province of Pakistan, 10,394 brick kilns are functional, of which 78% use old technologies. In the vicinity of Sargodha, there are around 403 brick kilns that use coal as their major source of energy for burning bricks (Ahmad et al., 2020). Thus, the market has a great potential to shift from conventional techniques towards using a sustainable green material, such as fly ash, which can help to save the environment (Farooq

& Yaqoob, 2019; Mukhtar et al., 2022; Akhtar et al., 2022). The purpose of the current research was to identify the stated gap of fly ash usage while producing concrete blocks in the brick kilns operating in Sargodha city. Fly ash containing blocks can be used in the construction industry at a comparative price through their marketing as a green product.

Materials and Methods

The research followed the standard process of brick formation, drawing upon the literature that was explored. (Singh et al., 2021; Pushpraj et al., 2015). In order to enable the utilization of local fly ash for green cement block design and development, the key factor was the availability of fly ash in the immediate context through its easy and sustainable supply. Fly ash was tested in the Engineering Lab of the Department of Civil Engineering, Sargodha University. The sites of brick kilns near Sargodha were established through site visits in order to gather an ample amount of material from these sites for lab-based testing.

Figure 1

Drying and Cleaning Process of Fly Ash

Samples of fly ash were collected physically from 15 identified sites around the vicinity of Sargodha city. The samples were transported for lab-based testing where they were used to develop a sustainable fly ash block for the local market. Powdered fly ash combined with dust stone and cement were manually mixed with water to get a homogenous mixture. The mixture was poured into an automatic block machine through a belt conveyor. Further, the blocks were placed on wooden pallets and retained in the same way for drying and water curing for 14 days. The cleaning, drying, and curing was done within the vicinity of the University of Sargodha, as shown in Figure 1. Then, compressive strength test and water absorption test were performed in the Engineering Lab of the University of Sargodha (Figure 2) to compare the new blocks with conventional clay bricks. The compressive strength of local bricks in Sargodha was recorded as 1833.0 PSI (Tariq et al., 2014).

Figure 2
Lab-based Testing and Preparation of Fly Ash Cement Blocks

Additionally, the quality and quantity of waste produced was determined during the sample collection phase with the help of a developed questionnaire and an open-ended discussion. A sample of 50 local suppliers and seller points from different buyers were selected to evaluate user performance and acceptability preference for the green product. The data helped in the identification of waste production at the selected sites in order to ensure the feasibility of the proposed product for market acceptability analysis. Since the research was conducted during the COVID-19 pandemic, therefore, the parameters of market study were based on the local market utilization of the proposed product, with better efficiency and usage leading towards better market share in the future. Hence, these results were later taken to multiple potential sellers to evaluate their feedback as product evaluation. However, since very limited construction was going on at that time, feedback was gathered from a limited audience consisting of the buyers/sellers of similar products.

The results from the selected sites showed the potential usage of the green product corresponding to the availability of raw material that can be used for the commercial development of green concrete blocks. The brick kiln industry adds hazardous gases and can be considered as one of the main contributors that pollute the local environment and deteriorate the air quality (Rauf et al., 2022). The basic raw material used for producing bricks is clay but fly ash turned out to be an environment friendly resource and a potential sustainable replacement for clay bricks (Moyo et al., 2019; Islam et al., 2020). The use of fly ash in brick kilns has the prospect to solve the issue of waste fly ash disposal (Rauf et al., 2022). Sampling techniques adopted for the current research were convenient and purposive sampling techniques. They aimed to ensure that data collection could be completed within the anticipated timeline and budget.

Results and Discussion

Four samples were prepared using varying proportions of fly ash. Curing time for each sample was 14 days at room temperature. The size of the fly ash cement block was kept the same as of locally available clay bricks, that is, 9”x4.5”x3”. The details of all the samples and their testing performance based on their compressive strength and water absorption are depicted in Table 1.

Primarily, two samples were developed (S1 and S2) and differentiated on the basis of the composition of materials. S1 had 70% fly ash composition with 20% stone dust, while S2 had 60% fly ash composition with 30% stone dust, respectively. The percentage of cement was fixed at 10% in the overall composition of the blocks. The average compressive strength of S1 was 2022 PSI (pounds per square inch), while the average compressive strength of S2 was 2257 PSI, which was higher than the recorded compressive strength of local clay bricks. Therefore, it was established that a higher value of fly ash in a composition provides better strength and outcome.

In case of water absorption, S1 had a percentage value of 13.54% on average, whereas the percentage value of S2 was 15.39%. These variations clearly showed that fly ash was able to provide a barrier to the water absorption capability of the brick. It showed a positive value for the water capacity to carry along the medium. Hence, the overall strength of the material and of the block itself was improved with a higher composition of fly ash. The dry weight to wet weight average in S1 was in the range of 3.53 Kg to 4.01 Kg, leading to a difference of 0.47 Kg, on average. Whereas, the dry weight to wet weight average in S2 was 3.62 Kg to 4.18 Kg, leading to a difference of 0.55 Kg, on average. Water absorption was calculated using a standard formula mentioned in equation 1 (Tariq et al., 2014).

Water absorption by weight (%) = (M_2 - M_1/ M_1) x 100,

where M_2 = Weight of Wet Brick Sample and M_1 = Weight of Dry Brick Sample

Table 1

Compressive Strength and Water Absorption Tests of Fly Ash Samples

Brick Samples for Fly Ash Brick	Composition of Materials			Strength (PSI) 03 Bricks		Brick Sample Water Absorption (M_2 - M_1/ M_1) x 100		
						Dry Weight (M_1)	Wet Weight (M_2)	Water Absorption
		%	kg			kg	kg	%
S1	Fly ash	70	6.68	S1-A	2015	3.4991	3.9545	13.01
	Stone dust	20	4.89	S1-B	2023	3.512	3.9912	13.64
	Cement	10	1.72	S1-C	2028	3.5989	4.1023	13.99
S2	Fly ash	60	5.73	S2-A	2263	3.6325	4.1815	15.11
	Stone dust	30	7.34	S2-B	2258	3.5989	4.1624	15.66
	Cement	10	1.72	S2-C	2250	3.6527	4.2151	15.40
S3	Fly ash	50	4.78	S3-A	1980	2.430	2.771	14.03
	Stone dust	40	8.10	S3-B	1998	2.512	2.871	14.29
	Cement	10	1.72	S3-C	1988	2.598	2.967	14.20
S4	Fly ash	40	3.82	S4-A	1834	1.826	2.131	16.68
	Stone dust	50	10.1	S4-B	1840	2.032	2.361	16.19
	Cement	10	1.72	S4-C	1838	1.969	2.299	16.76

Henceforth, based on the average calculation of the differences of means in weights for S1 and S2 sample blocks, it became evident that fly ash composition not only gave better bonding but also gave higher strength to the material and to the block itself. Two more samples were developed and explored. However, due to a higher water absorption ratio, they were not considered and explored further.

The current research also explored the attainment of market share with the created product, if introduced in the local market, versus the locally produced clay bricks. Clay bricks cause environmental pollution and are not considered green due to extraction and land degradation. In order to carry out this phase of research, six (06) vendors were identified in different locations of the city where they either manufactured or supplied locally produced clay bricks to the local market. Apart from these six vendors, six (06) direct buyers were also approached through open market to evaluate the current market conditions along with the perception of local buyers towards green fly ash cement block. Figure 3 provides the pictorial reference of interviewing the respondents in the local market.

Figure 3

Visits of Local Market for Feasibility Analysis

Vendors, suppliers, manufacturers, and local buyers were approached on their respective construction sites during August 2020. At that time, the monsoon season was at its peak and was close to end soon in the following month of September. Consequently, the need of cement and the demand for bricks were on the rise in the local market. In order to gauge the popularity and acceptability of the green fly ash cement block amongst the respondents, an interview-based mode with pre-defined questions posed in a structured way was used to gather ample information, as shown in Table

2. In order to gather the required data, the following major questions were asked and the responses were noted manually.

Table 2

Responses of Vendors/Suppliers/Manufacturers

S. No.	Questions for Vendors/ Suppliers/Manufacturers	Reponses
1	Have you heard of fly ash usage in construction products such as bricks or cement blocks?	All six (06) vendors agreed that they have heard of similar products being sold in the markets of bigger cities such as Lahore and Karachi but have not seen them in Sargodha city.
2	Have you ever used/marketed/sold such a product previously or not?	All responded that they have neither procured nor supplied such a product previously in the local market.
3	If such a product is available at a lower cost as compared to the current market price, would you like to use it?	Five (05) out of six (06) respondents agreed to keep at least 100 blocks as samples in order to market or showcase them but none of them were willing to place an order.
4	Do you think that the market would accept the product in the current scenario of market decline due to COVID-19?	Four (04) out of six (06) respondents agreed that local market would accept it if it is used in multiple projects and the projects or the usage of the product in these projects can be shown. Apart from it, copies of lab-based test reports should also be provided, so that people could be convinced about the quality of the blocks.
5	Do you have any concerns/queries related to the product you have seen?	There were few concerns which were common to all, such as the profit margin they would have for each sale of a block, how the researcher would be able to supply large orders, can they visit the manufacturing plant of the blocks, and would the blocks be available in different sizes, colors, and textures as existing cement blocks are available.

Also, the responses of the buyers and consumers were recorded through structured questions about their acceptability related to the new material. The responses of the buyers are shown below in Table 3.

Table 3
Responses of Buyers/Consumers

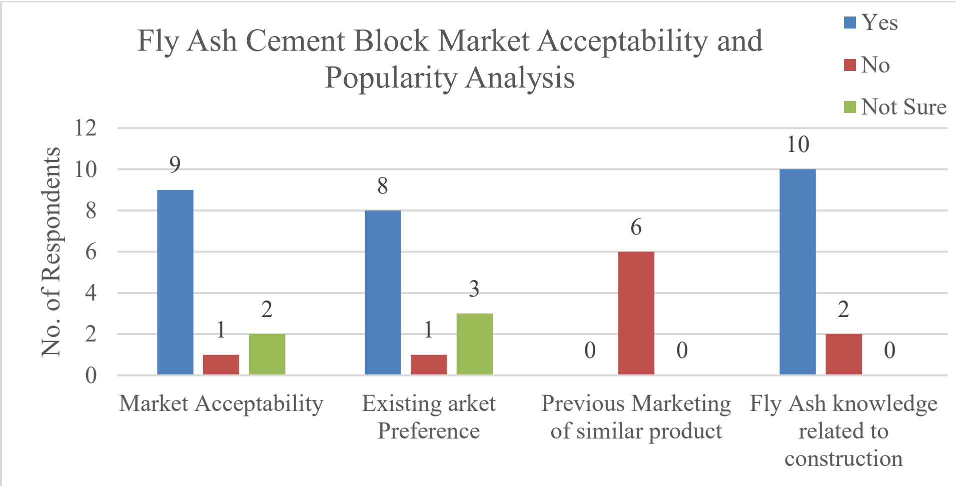
S. No.	Questions for Consumers/Buyers	Reponses
1	Have you heard of fly ash usage in construction products such as bricks or cement blocks?	Four (04) out of six (06) respondents never heard of fly ash usage in cement based products related to construction industry.
2	If such a product is available at a lower cost as compared to the existing market price, would you like to use it?	The researcher could show them any building(s) where they have been used previously and the owner of the building can guarantee that the product is better than the local bricks available in the market.
3	Do you think that the market would accept the product in the current scenario of market decline due to COVID-19?	Three (03) out of six (06) respondents agreed that this would make a better option due to the poor economic condition of the market, while the remaining three were not sure about it.
4	Do you have any concerns/queries related to the product you have seen?	They mainly asked about the price, overall strength, and availability in the long run. Their major concern was any case study in the local context where the same block had been used.

It is evident that although people were willing to opt for new products, still they were reluctant due to the poor economic condition caused by the COVID-19 pandemic, non-availability of the existing usage of these specialized blocks in any local building, and concerns regarding how the supply chain process would be managed. The following Figure 5 depicts the acceptability and popularity of the newly developed green fly ash cement block in the market.

The data was collected from six (06) vendors and six (06) local buyers operating in Sargodha city to explore the potential and popularity of fly ash cement blocks for construction purposes. Higher fly ash values yielded better compressive strength and were also able to reduce water absorption, yielding it as a better option in the overall fly ash usage which is also beneficial for the betterment of the local environment, rather than throwing it away in open environment.

Figure 5

Fly Ash Cement Block Acceptability and Popularity Analysis



Based on the market study, it was observed that currently the local market is not using any similar products but is aware of potential products which might be available in bigger cities and urban centers. It was also observed that people were unable to either market the product or to keep the samples due to the lack of its usage in any building construction project or site previously. They required a case study or people who have already used it to vouch for it. Then, they would keep its samples for marketing and business development opportunities. Local buyers on the construction sites expressed similar views, except that one buyer did want to check the product by installing it in the boundary wall, rather than using it in the main structure of the building. His main concern was to have sufficient number of blocks ready in the next five days, which was not feasible and outside the scope of the current study. Hence, it was not explored any further as it did provide an opportunity to initiate the local market

It was also concluded that due to the COVID-19 pandemic, the market was not favorable towards any major business venture or exploration. Hence, people were also unwilling to participate in any risk-based business. The area has the potential of brick production since it has 403 functional brick kilns and each brick kiln has the capacity to produce 10,000-20,000 bricks per day. Once the market regains its momentum during or post pandemic times, there would be a higher value generation and an opportunity to capture a share in the local market. One major concern was the continuous supply of fly ash through a sustainable resource which was lacking at the moment in the University of Sargodha from where the fly ash was gathered. Secondly, a proper production plant for the product would be required to ensure its market availability. Without a proper manufacturing plant and production unit, the market once tapped might not be able to deliver ample returns and profits, especially if the share is missed due to the failure to produce enough green products to meet the market demand and manage the supply chain process.

Conclusion

Each kiln produces 10-12 kg of fly ash on average on a daily basis. Since most of it is either wasted or thrown away in open environment, there is a good potential to use this waste in developing green products related to concrete and made of fly ash. It must be kept in consideration that data collection was done during the pandemic, hence the kilns were not operating optimally. Based on laboratory testing with multiple compositions, 60-70% fly ash addition with 10% fixed cement ratio provided the sample with a compressive strength of more than 2200 PSI. Furthermore, it also provided the sample with 12% to 15% water absorption test values which suits the building construction purposes. Also, the cost of fly ash blocks is less than the local bricks. Hence, they are a suitable material in terms of their strength for use in construction along with their added environmental benefits.

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