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A Critical Review of the Potential for Fly Ash Utilisation in Construction-Specific Applications in India

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In India, coal-fired power plants produce about 196 million tonnes of fly ash annually. The management of fly ash has thus been a matter of concern given the requirement of the large area of land for its disposal and potential of causing pollution of air and water. Various initiatives have been taken in the country to promote safe utilisation of fly ash. But despite these initiatives, the optimal utilisation is yet to be achieved. Most of the existing literature is related to forecasting the utilisation of fly ash in different modes and accordingly presents the promising applications, but the latent utilisation potential of applications is not yet explored. In this paper, the potential of fly ash utilisation in various construction-specific applications, i.e., cement, concrete, brick, and blocks, has been estimated through a simple framework. The study reveals that although cement is one of the most prominent applications where fly ash has been significantly utilised, it reached its threshold limit of utilisation. The scope of utilisation of fly ash in cement in the future is limited only to the extent of the rate of increase in cement consumption. The potential of fly ash utilisation in concrete is significantly higher, as the projected growth rate of ready-mix concrete (RMC) is moving upwards. However, this increased percentage of RMC will not impact much on overall fly ash utilisation as this will only balance out the share percentage of overall cement requirement. In this study, the bricks/blocks emerged out to be the application having a maximum consumption potential. This study further explores the reasons behind the sluggish performance of fly ash bricks and blocks in the market and suggests strategies for policy-level interventions that can accelerate the process of successful commercialisation.

Keywords: fly ash utilisation, consumption potential, promising applications, cement and concrete, bricks, blocks.

Introduction

India is undergoing rapid urbanisation, and with 31.8% of India's population in urban areas as per Census 2011, this number is expected to reach 40% by 2030, contributing to 75% of India's Gross Domestic Product (GDP). The rural population is migrating to the cities with the rapid industrialisation in developing countries, (Kumar, 2003). With a vision to provide housing for all by 2022, the Government of India (GoI) launched mission *Pradhan Mantri Awas Yojna* ("Housing for All") (Yojana, 2015). Under this mission, the GoI aims to construct one crore (about 10 million) of housing units by the year 2022. This results in enhanced construction activities, a shortage of conventional building materials, and increase in the quantity of wastes and pollution levels. To ensure sustainable growth, urban cities need to provide a receptive, innovative, and productive environment for a better quality of living.

India's burgeoning demand for materials and energy due to the high rate of construction works puts serious constraints on natural resources such as land, water, minerals, and fossil fuels. This results in driving up energy and commodity prices. On this note, there is a need to develop and pursue manufacturing activities, which could help in maximising economic and social benefits along with minimising environmental impact.

To balance this rapid urbanisation, the per capita electricity consumption in India follows the upward curve. As per the recent report by the Central Electricity Authority (CEA), about 57% of the total power generated in India is produced by coal-based power plants (Authority C. E., 2018). Globally, coal provides around 27% of overall energy supplies and generates about 38% of the world's electricity, and this proportion is expected to remain static for the next 30 years (Association, 2019). At present, there are 167 active coal/lignite-based thermal power stations in India that consume about 625 million tonnes of coal (around three-fourths of the total coal used in the country). This has resulted in the production of a huge quantity of fly ash, which is approximately 196 million tonnes in 2017–2018. With the increasing demand for electricity and coal being the major source of energy, the generation of fly ash has been increasing and predicted to continue to increase in the future (Kumar, 2005). To meet the growing energy demand of the country, coal-based thermal power generation is expected to play a dominant role in the future as well, since coal reserves in India are expected to last for more than 100 years.

The disposal of such a large quantity of fly ash is indeed a challenge before all stakeholders. Various initiatives were taken by the government, several non-government organisations, and research and development organisations for fly ash utilisation, resulting in the increase in the utilisation of fly ash from 6.64 million tonnes in 1996–1997 to a level of 131.86 million tonne in 2017–2018. To further promote the utilisation, the Ministry of Environment, Forest and Climate Change (MOEF(CC), 2016) in its latest notification, mentioned that the new coal thermal power plants are required to use 100% of the fly ash produced within nine years of commencing operation. Also, it mandated the use of fly ash and its products for any construction activity within a vicinity of 300 km from the thermal power plant.

Despite several initiatives, taken at the policy level by various ministries and a large number of technological development by the various R&D organisations for gainful utilisation, the current percentage utilisation (67.13%) (Authority C. E., 2018) is quite behind the target. Table 1 highlights the *Modes of fly ash utilisation in China and India*, the top two countries based on annual fly ash generation. It is evident from Table 1 that fly-ash is used in numerous sectors with the majority of applications in construction and related activities. Currently in India, 38.67% of fly ash is utilised in the construction sector for various modes like 25.60% in cement, 9.01% in bricks and tiles, 3.40% in roads and flyovers, and 0.66% in concrete. Comparing it with China, the percentage of fly ash utilisation in India is far behind in modes like cement, concrete, bricks, and tiles. For the adoption of safe and economically viable alternative(s) of fly ash utilisation, all potential fly ash utilisation modes must be identified and analysed to enable the formulation and implementation of a proper plan of action. Thus, in this paper, an attempt has been made to quantify the utilisation potential of fly ash in applications like cement, concrete, bricks, and tiles since these modes have the potential to accommodate a major portion of the fly ash generated.

Table 1. *Modes of fly ash utilisation in India (Authority C. E., 2018) and China (Ma, 2017; He, 2012)*

S. No.	Mode of Utilisation	India (2017–2018)	China (2015–2016)
		% Utilisation	% Utilisation
1	Cement	25.60%	30.80%
2	Mine filling	6.37%	-
3	Bricks and tiles	9.01%	19.60%
4	Reclamation of low-lying area	10.48%	-
5	Ash dyke raising	6.90%	-
6	Roads and flyovers	3.40%	3.50%
7	Agriculture	0.29%	2.10%
8	Concrete	0.66%	11.20%
9	Hydropower sector	0.00%	-
10	Others	4.42%	2.80%
11	Unutilised	32.87%	30%
	Total	**100%**	**100%**

Methodology

There is a long list of applications for fly ash utilisation. However, no single application can ensure 100% use of fly ash. Therefore, a judicious mix of applications is necessary. The literature review reveals that the use of fly ash has been steadily increasing over the years. Therefore, this study aims to identify promising applications that can contribute significantly to maximising fly ash utilisation in the future.

To achieve the level of 100% utilisation mandated by MOEF(CC) (2009), a prudent mix of different applications according to their potential needs to be identified (Loya, 2014). The time series model was used by the various researchers to predict the future utilisation quantities considering past trends (Bhattacharjee, 2002; Loya, 2014; Loya, 2015). Bhattacharjee (2002) have presented various equations to predict the quantum of fly ash utilisation in cement, bricks, roads, and flyovers. He has used linear regression, a variant of the time series model to calculate many factors in these equations. However, several underutilised applications cannot be predicted using this model due to the absence of data on past trends. Loya (2014) in his study identified mine filling, bricks, and tiles; and roads and embankments are the applications that have large potentials but are yet to be actualised. Hence, this study aims to estimate the latent potential of fly ash utilisation in construction sector-specific applications like the production of cement, concrete, bricks, and blocks and then investigate the reasons behind the underutilisation of fly ash in these applications. The study begins with the assessment of fly ash generation and utilisation for the next decade. A simple equation based on compounded annual growth rates (CAGR) is presented for this purpose. Subsequently, section *"Utilisation potential in cement and concrete"* presents calculations to predict the utilisation of fly ash in cement and concrete that are based on the equations given by Bhattacharjee (2002). Section "*Utilisation potential in bricks and blocks*" illustrates the potential of fly ash utilisation in bricks and blocks by analysing the data obtained from various literature sources. Accordingly, suggestions for necessary amendments in guidelines and policy-level interventions have been presented to promote fly ash utilisation in the potential area.

Fly ash generation and utilisation

About 76% of the total power generated in India is produced by coal-based power plants. At present, there are 167 coal/lignite-based thermal power stations in India that consume around 625 million tonnes of coal annually. With the increasing consumption of coal, fly ash has become one of the largest industrial solid waste in India. Figure 1 shows the generation and utilisation of fly ash in India from 1996 to 2018.

Annual fly ash generation is still increasing and expected to reach 300 Mt by 2027[1]. Although there are still no accurate statistics for the next future years, the figure is thought to grow further slowly and the output of fly ash will remain the level of 300~350 MT. The problem becomes more serious while considering the stockpiled quantity of unutilised fly ash stored in ash ponds near the thermal power plants. Table 2. Estimated stockpiled

[1] Calculated, considering 877 MT of coal till 2026–2027 as per National Electricity Plan, Jan 2018 and 33% average ash content in coal (Authority C. E., 2018).

Fig. 1. *Fly ash generated vs fly ash utilised in India (Source: Author (compiled from CEA Reports: 1996–2018))*

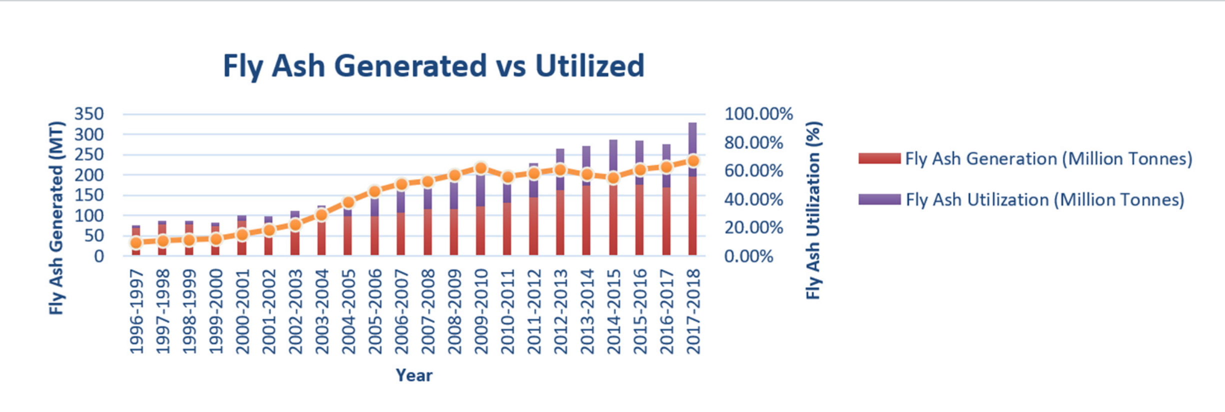

Table 2. *Estimated stockpiled quantity of fly ash (Source: author (compiled from CEA Reports from 1996–2018))*

S.No.	Year	Fly Ash Generation (Million Tonnes)	Fly Ash Utilisation (Million Tonnes)	Fly Ash Utilisation (%)	Stockpiled Fly Ash (Million Tonnes)
1	1996–1997	68.88	6.64	9.64%	62.24
2	1997–1998	78.06	8.43	10.80%	69.63
3	1998–1999	78.99	9.22	11.67%	69.77
4	1999–2000	74.03	8.91	12.04%	65.12
5	2000–2001	86.29	13.54	15.69%	72.75
6	2001–2002	82.81	15.57	18.80%	67.24
7	2002–2003	91.65	20.79	22.68%	70.86
8	2003–2004	96.28	28.29	29.38%	67.99
9	2004–2005	98.57	37.49	38.03%	61.08
10	2005–2006	98.97	45.22	45.69%	53.75
11	2006–2007	108.15	55.01	50.86%	53.14
12	2007–2008	116.94	61.98	53.00%	54.96
13	2008–2009	116.69	66.64	57.11%	50.05
14	2009–2010	123.54	77.33	62.60%	46.21
15	2010–2011	131.09	73.13	55.79%	57.96
16	2011–2012	145.41	85.05	58.49%	60.36
17	2012–2013	163.56	100.37	61.37%	63.19
18	2013–2014	172.87	99.62	57.63%	73.25
19	2014–2015	184.14	102.54	55.69%	81.6
20	2015–2016	176.74	107.77	60.98%	68.97
21	2016–2017	169.25	107.1	63.28%	62.15
22	2017–2018	196.44	131.87	67.13%	64.57
Total quantity of stockpiled fly ash					**1396.84**

quantity of fly ash (Source: author (compiled from CEA Reports from 1996–2018)) shows that approximately 1,400 million tonnes of fly ash is estimated to be stockpiled in ash ponds across India, which is almost seven times than of its annual generation.

Utilisation potential in cement and concrete

Fly ash utilisation in cement can be done in two ways: 1) in the production of pozzolana Portland cement (PPC) itself and 2) as an admixture along with ordinary Portland cement (OPC), aggregates, and water in design mix concrete. China and India are two major markets of fly ash generation and cement production in the world. India ranks second after China in both cement production and fly ash generation. **All the quantities are in million tonnes* below presents the comparative analysis of both the countries in terms of cement produced and fly ash utilized.

Analysis of the data of two countries shows that the overall percentage of fly ash utilisation vs its generation in cement and concrete together is more in China (42%) compared to India (26.62%). But even then India (18.44%) exhibits more percentage of fly ash utilisation in overall cement production than China (10.72%). However, analysing the cement sector alone shows that the percentage utilisation of fly ash in cement is even better approximately around 25% (considering 70% PPC share).

In future, cement production will be driven by factors like environmental issues, economic issues, conservation of materials, and energy-saving (Jain, 2016). As per World Business Council for Sustainable Development (WBCSD, 2018), the cement sector is expected to keep growing in between 6–7% until 2030 and follow a current low-carbon pathway. There is a substantial reduction in carbon emissions intensity from 2010 to 2019 in the manufacturing of cement. The reduction is mainly due to an increase in alternative fuel use, reductions in the clinker factor, and increases in blended cement production. The share of blended cement in the total quantity of cement manufactured in India in 2010 was 68% (Kulkarni, 2012). This increased to 73% of the total cement production in 2017, largely due to the market's growing acceptance of blended cement, emerging awareness of sustainability concepts, the availability of fly ash from thermal power plants, and the use of advanced technology. The production of pozzolana Portland cement (PPC) grew from 66.5% in 2010 to 70% in 2019 (Foundation, 2019). The percentage of PPC in the total cement production in India is likely to remain within the range of 65% to 70% in future years (Jain, 2016). The annual cement production (in million tonnes) in any specific (nth) year is estimated using the below equation:

$$EQ_{Cement}(n) = Q_{Cement}^{(cn)} X (1 + Gr_{Cement})^n \quad (1)$$

Where $EQ_{Cement}(n)$ is the quantity of cement produced, to be estimated in the nth year, $Q_{Cement}^{(cn)}$ is the quantity of cement produced in the current year (cn), Gr_{Cement} is the annual growth rate of cement, and n is the no. of years for which the quantity of cement is estimated.

It is assumed that initially at (n = 0), $p_{fa}(c)$ is the current percentage utilisation of fly ash in cement which is expected to increase linearly from $p_{fa}(c)$ to $p_{fa}^n(t)$ in N years; thus, the projected percentage of fly ash utilisation $P_{fa}^n(pr)$ for an nth year can be estimated as:

$$P_{fa}^n(pr) = p_{fa}(c) + \left(\frac{p_{fa}^n(t) - p_{fa}(c)}{N}\right) * n \quad (2)$$

Table 3. *Percentage of fly ash utilised in cement production: India vs China (source: author)*

Countries	Quantity of Cement Produced	Quantity of Fly ash Utilised (in cement)	Quantity of Fly ash Utilised (in concrete)	Total % of fly ash utilised in cement & concrete
India (2017–2018)	279.81	50.29	1.3	18.44%
China (2015–2016)	2350	184.8	67.2	10.72%

**All the quantities are in million tonnes*

Table 4. *Estimated utilisation of fly ash in cement production until 2030 (source: author)*

Year	Total Cement Production (in Million Tonnes)	PPC % of Total Cement Production	PPC Production (in Million Tonnes)	Fly ash Utilisation (in Million Tonnes)
2010	206.6	66.50%	137.39	35.47
2011	216	65.50%	141.48	38.08
2012	230.49	66%	152.12	41.33
2013	248.23	65.50%	162.59	39.17
2014	255.83	66%	168.85	43.33
2015	270.04	66%	178.23	43.37
2016	283.46	67%	189.92	40.59
2017	279.81	70%	195.87	50.29
2018	297.56	70%	208.29	54.17
2019	304.2	70%	212.94	56.09
2020	324.28	70%	226.99	60.54
2021	345.68	70%	241.98	65.35
2022	368.49	70%	257.95	70.52
2023	392.81	70%	274.97	76.08
2024	418.74	70%	293.12	82.08
2025	446.38	70%	312.46	88.53
2026	475.84	70%	333.09	95.48
2027	507.24	70%	355.07	102.96
2028	540.72	70%	378.51	111.02
2029	576.41	70%	403.49	119.69
2030	614.45	70%	430.12	129.02

Putting figures in Equation (1) and (2), Table 4 presents the estimated quantity of cement production, percentage of PPC, and fly ash utilisation from the year 2018 to 2030.

For quantitative analysis, the compounded annual growth rate (CAGR) of 6.6 % is considered for cement production (Shiv Sharma, 2018), and 70% PPC percentage is considered (Jain, 2016). The fly ash utilisation percentage is assumed to be targeted $p_{fa}(t)$ at 30% until the end of year 2030. The annual fly ash generation is expected to reach 350 MT by 2030. While cement's fly ash requirement will be expected to grow more than two-fold, i.e., from 50.29 MT to 129.02 MT, yet to achieve the target of 100% ash utilisation, approximately 221 MT of fly ash will still have to be utilised in other modes.

On the other hand, the fly ash utilisation in concrete is subjected to a) producing design mix concrete by batching plants installed at construction sites, and b) ordering the concrete as per requirement from nearby ready mix concrete plants. The first one is less preferred as its feasibility depends upon the availability of upfront capital cost to set up batching plant at the site, daily concrete requirement, and well-equipped lab and resources to ensure the quality of produced concrete. Meanwhile ordering concrete from RMCs is rather quite easy owing to the ease of use, economic, greater convenience, and improved quality. The low inventory costs and reduction of wastage are further resulting in the reduction of the total project expenses. Ready-mix concrete (RMC) can be defined as a mixture of water, cement, aggregates, and sand. The manufacturing of ready-mix concrete and delivering it through a transit mixer allows the integration of precise concrete in construction, thus making it strong, sturdy, and long-lasting.

Despite these benefits, the percentage of cement consumed in the RMC sector is quite low. While in India it stands around 7–8% of the total quantity of cement produced during 2010–2011, at the same time this percentage is much higher in other countries and varies from around 48% in Europe to 73% in the USA. However, Market Research Future (MRFR, 2020) proclaims that the global ready-mix concrete market is anticipated to register a CAGR of 8.02% during the forecast period (2017–2023). Yet, this increased percentage of RMC will not impact much on fly ash utilisation as this will only replace the share percentage of PPC cement to balance out the overall cement requirement.

Thus, it is comprehended that the cement and concrete alone would not be able to utilise the increased volumes of fly ash in the future and new avenues have to be found and promoted.

Utilisation potential in bricks and blocks

The ever-growing population and the demand for the construction material resulted in more production of bricks. In a study done by the *Material Consumption Patterns in India (2016),* there exists an increasing gap in demand and supply of different building materials. The basic building materials like cement, bricks, steel, and lime account for more than 80% of the emissions in the construction (Reddy & Jagdish, 2003). Although all building materials are pollution-intensive, the contribution of burnt bricks is very significant to the environmental impacts. It is estimated that presently about 860 million tonnes of materials are consumed per year to produce different kinds of bricks in India. The brick sector is also one of the largest emitters of greenhouse gases. About 66–84 million tonnes of CO_2 and over 1,00,000 tonnes of black carbon are emitted every year from brick kilns (Shakti Foundation, 2017).

Production of bricks is resource-intensive, consuming large quantities of raw materials; Greentech Knowledge Solutions Pvt. Ltd. (GKSPL, 2016) estimated the consumption of about 750 million tonnes of soil; 30 million tonnes of coal and 10 million tonnes of biomass annually in the production of burnt clay bricks that make the brick industry one of the largest energy-consuming industries in the country. Apart from this, 60 million tonnes of stone aggregates and sand, 17 million tonnes of fly ash and 5 to 10 million tonnes of cement and lime are used annually to produce fly ash bricks, AAC blocks, and concrete blocks.

Masonry construction using bricks is the main type of building construction technology used in the country. Among various types of bricks, solid burnt clay bricks are the most widely used bricks. In recent years, several new walling construction technologies and materials have been introduced, but in the foreseeable future, bricks are expected to retain their dominant position (BMTPC, 2016). Given the largely anticipated growth in the building construction, it is expected that in the next 15 years, masonry construction will retain its dominant position, and the average annual demand for bricks in India will increase from around 250 billion Standard Brick Units (SBUs) a year during 2012–2017 to a peak of around 750–1000 billion SBUs a year during 2032–2037 (GKSPL, 2016). The solid burnt clay bricks hold the largest production share of about 89%. Concrete blocks, AAC blocks, and fly ash lime/cement bricks are other major types of bricks, accounting together for a share of about 10% in overall bricks production.

Masonry construction using bricks is the dominant form of house construction in India, accounting for 58.3% of the households as per Census (2011). Burnt clay brick is the most popular walling material, accounting for 48% of the households. Census data from 1991–2011 show that burnt bricks are increasingly used in both rural and urban areas as wall material due to which the annual production of bricks has increased six times during the past 40 years.

Like every other industry, the construction industry is also developing new technologies to meet its ever-growing demands. The innovations in the construction industry have led to the development of various alternative construction systems. The application of alternative construction systems such as monolithic concrete construction and construction using prefabricated concrete panels as a replacement for masonry is being promoted by the Government of India, particularly for mass housing (BMTPC, 2016). However, their penetration, though increasing, is still low and is confined to a section of the organised construction industry only.

As per the current trend, resource consumption and emissions are projected to increase four-fold in the next 20 years as the annual demand for bricks is expected to quadruple during this period. It is, therefore, imperative to start deliberating about resource-efficient bricks both from the demand as well as the supply side (Shakti Foundation, 2017).

Focussing to minimise resource consumption and emissions, the Government of India initiated the fly ash utilisation in the production of bricks and blocks through various regulations. The first regulation for fly ash utilisation was notified in 1999, which have subsequently been revised in 2003, 2009, and 2016 (MOEF(CC), 1999, 2003, 2009, 2016). The revised 2016 regulation aims at replacing the majority of burnt/red clay brick production in the country with fly ash bricks and blocks (having minimum 50% fly ash by weight). To achieve this objective, the regulation states the following.

a Mandating red clay brick manufacturing units to shift to fly ash brick manufacturing.

The regulation proposes that within a 300 km radius of a coal- or lignite-based thermal power plant, no new red clay brick kiln shall be installed, and all existing red clay brick kilns located within 300 km shall be converted to fly ash brick or block manufacturing unit within one year. If we draw a 300 km radius around thermal power plants on a map of India, it practically covers the entire country (barring some parts of North-East India and the Himalayan region). Thus, the regulation proposes that 150,000–200,000 existing red clay brick making units (having an annual production capacity of 20,000–25,000 crore bricks/year) should change their manufacturing technology and shift to fly ash brick and block manufacturing within one year. If this regulation is implemented in true sense, then the annual fly ash utilisation would be around 149–186 million tonnes, assuming that one fly ash brick (size: 230 x 120 x 75 mm) weighs 2.5 kg and consists of 30% average fly ash content by weight per brick. In this situation, the required amount of ash is about 3 times the annual unutilised quantity of fly ash, which is practically feasible only if the existing pond ash is made available for making fly ash bricks. This will not only achieve the target of cent percent utilisation of fly ash generated but will also fully utilise the stockpiled pond ash in the next 15–20 years.

b Mandating thermal power plants to supply fly ash to fly ash brick manufacturing units

As per Central Electricity Authority data, around 9% of the annual fly ash generation was supplied to bricks and blocks manufacturing units which resulted in the production of around 1,300 crore fly ash bricks and blocks (Authority C. E., 2018). One of the main problems being faced by the existing small-scale fly ash brick and block manufacturing units is in getting adequate, affordable, and uninterrupted supply of fly ash. In a bid to address these supply-side issues, the draft regulation proposes following mandatory requirements on thermal power plants:

- thermal power plants to make available at least 20% of dry ESP fly ash to the units manufacturing fly ash bricks, blocks, and tiles;
- thermal power plants to supply fly ash at almost zero price (@ Rs 1/ton) as well as to bear the full cost of transportation of fly ash to fly ash brick manufacturing units located up to 300 km from the power plant.

Even if all thermal power plants can supply 20% dry ESP fly ash generated annually for brick production, the total quantity of fly ash available for brick production will be around 39 million tonnes a year. This quantity will be sufficient for making 45–55 billion bricks a year and can meet only 16.5% of the total current annual requirement for bricks.

Results and discussion

Cement and concrete

It is evident from Table 4. Estimated utilisation of fly ash in cement production until 2030 (source: author) that although there is a substantial increment in the fly ash utilisation in cement, yet the PPC share has reached its threshold limit in thed total cement production in India, and new initiatives are required to increase the utilisation of fly ash. The scope of utilisation of fly ash in cement in the future is limited only to the extent of the rate of increase in cement consumption. In case the growth of the cement sector in the future is lower than the expected CAGR of 6.6%, then the quantity of unutilised fly ash would be more than the expected.

The situation will not change much even after considering the fly ash utilisation in concrete. Although it is anticipated that the concrete sector will grow at a CAGR of 8.02% in the following years, which subsequently increases fly ash utilisation, yet this increased percentage of RMC will not impact much on fly ash utilisation as this will only replace the share percentage of PPC cement to balance out the overall cement requirement.

Bricks and blocks

The results achieved from the analyses of MoEF (CC) regulations in section *"Utilization Potential in Bricks and Blocks"* show a clear contradiction. As calculated from the first regulation, the quantity of fly ash required to achieve the 300 km criterion is estimated to be in the range of 149–186 million tonnes in a year whereas the thermal power plants are liable to provide only 39 million tonnes of fly ash to bricks/blocks manufacturing units as per second regulation. Secondly, the fly ash availability is highly skewed among states (Ahmad, 2014). Several states are having almost no or a very little amount of fly ash available for brick making, hence the mandate to supply at least 20% of fly ash by the thermal power plants uniformly throughout the country is not practical.

The analysis shows that the quantity of fly ash that could be made available for the units manufacturing bricks will be sufficient only to replace a fraction, i.e., 16.5% of the current burnt/red clay brick production in the country. Even reaching these replacement levels will be challenging due to regional disparities in the availability of fly ash and the demand for bricks. The steady increase in demand for bricks until 2050 and stagnation in coal-based thermal power generation in the near future may make meeting these replacement levels even more challenging. In light of the above findings, both the regulations do not seem to be feasible.

Various other issues need to be incorporated while amending the current notifications. Some of these are related to issues of implementation and market, e.g., a lack of awareness and negative perception about fly ash bricks, distributed nature of the brick industry, a lack of fiscal incentives for fly ash brick makers, and problems with fly ash sourcing (Shakti Foundation, 2017). Fly ash is a raw material required for the manufacturing of ash bricks, and any kind of disruption in its supply develops skepticism against the manufacturers for setting up these units. There are multiple stakeholders such as MoEF(CC), central pollution control board (CPCB), state pollution control board (SPCB), thermal power plants, and municipal corporations, which must work together to implement the fly ash regulations. The limited effectiveness of the fly ash regulations indicates that either there is a lack of clarity on the roles, responsibilities, and coordinating mechanism in the fly ash regulation or the arrangements suggested in the fly ash regulations are not practical. As per Bhattacharjee (2002), the key problems associated with the low level of fly ash utilisation include inconsistency in the quality of the fly ash produced (even from the same power plant) as the quality of coal received by power stations may vary considerably, the costs involved in the transportation of fly ash from the power plants to the consumption points, and consumer preference for products made from fresh materials over those produced from recycled wastes.

Conclusions

Despite shifting the energy generation modes from thermal to other renewable sources, the dependence on coal is expected to be significant in the next decade. This results in a substantial amount of fly ash generation and the ways need to be explored for its better utilisation. This paper analyses the true potential of ash utilisation in various construction sector-specific applications such as cement, concrete, bricks, and blocks using a simple framework. The results obtained for the projected level of ash utilisation until 2030 show that cement and concrete have reached the threshold limit and will not accommodate more than 35–40% of overall ash generated in the upcoming years. In this study, bricks and blocks emerged out to have the most potential mode which can easily accommodate the annual unutilised quantity of fly ash as well as also fully utilise the stockpiled pond ash in the next 15–20 years. This paper reviews existing MoEF (CC) policies for the promotion of fly ash utilisation in bricks and blocks, from which the contradiction between these policies is clearly evident. In addition to policy level challenges, this paper also identifies a lack of awareness of fly ash bricks, inconsistent quality of fly ash, a lack of incentive for manufacturers, high transport costs of fly ash and hesitation in adopting these bricks by consumers, etc., as some technical and market-related barriers associated with low fly ash utilisation in bricks and blocks. This research suggests that all associated stakeholders must work together to upgrade the existing policies required for the successful commercialisation of these products in the market. This study forms a base for future research in which the barriers of fly ash utilisation need to be investigated more comprehensively and accordingly a plan of action can be worked out to improve the fly ash utilisation in the identified application, i.e., bricks and blocks.

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