Chapter 10
Ash Utilization Strategy in India—A Way Forward

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10.1 Introduction

10.1.1 Ash Generation from Thermal Power Plants

The increase in Indian population over the past decades, the electrical energy obtained from coal-based thermal power plants as of now is at an all-time high due to which there is a serious enhancement in the generation of ash thereby creating environmental concerns for its disposal. The ash generated from thermal power plant are mainly fly ash and of total generated ash; about 20–25% is bottom ash. The slurry part disposed off in pond or dykes which is mixture of fly ash and bottom ash is termed as pond ash. Due to low pozzolanic property of pond ash, it is not suitable as part replacement of cement. Apart from being a management challenge for plant operators, such vast quantities of ash itself poses several public health challenges for communities living around the ash disposal sites. Just in terms of land use the conventional disposal of flyash in form of slurry currently occupies nearly 40000 hectares of land and require about 1040 mn m^3 of water annually (Soundaram et al. 2020; Anon 2019). The Ministry of Environment, Forest, and Climate Change vide notification dated 14th September 1999 and subsequent amendments in year 2003, 2009, and 2016 has emphasized 100% fly ash utilization to lower the impact on environment (MOEF 1999). As per the current estimates of Central Electricity Authority (CEA) (CEA Report 2018–2019), Indian power plants generated 217.04 million metric tonnes of ash in the year 2018–2019 due to coal or lignite combustion of about 667.43

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Table 10.1 Fly ash consumption in India as per Central Electricity Authority (CEA) (AS 3582.1)

Year	Parameter				
	Thermal power Stations (Nos.)	Coal consumption (Million Tons)	Ash production (Million Tons)	Ash utilization (Million Tons)	% Utilization
2014–2015	145.00	549.72	184.14	102.54	55.69
2015–2016	151.00	536.64	176.74	107.77	60.97
2016–2017	155.00	536.40	169.25	107.10	63.28
2017–2018	167.00	624.88	196.44	131.87	67.13
2018–2019	195.00	667.43	217.04	168.40	77.59

million tonne. The data published by the CEA indicates 78% ash utilization in year 2018–2019 (Table 10.1).

10.1.2 *Trends in Ash Utilization in India*

As per document by Soundaram et al. (2020), titled "An Ashen Legacy: India's thermal power ash mismanagement", states like Uttar Pradesh and Chhattisgarh generates the highest ash quantity compared to other states like West Bengal, Maharashtra, Andhra Pradesh, Madhya Pradesh and Odisha. All these states have large quantity of unutilized ash accumulated over a last decade as the power generation plants are coal based. The actual ash utilization in different major sectors in India is given in Fig. 10.1. In the report submitted to National Green Tribunal (NGT), total unused quantity of ash from coal power sector is about 1650 million tonnes. Out of

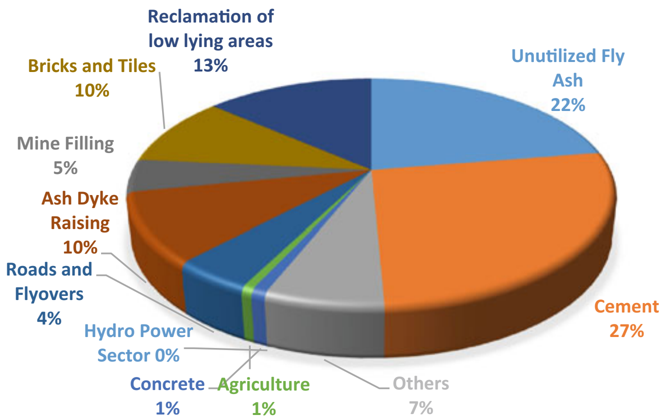

Fig. 10.1 Sector-wise ash utilization during the year 2018–2019 (CEA annual report 2018–2019)

186 power plants, only 103 power plants have been able to achieve full ash utilization whereas remaining power plants were not able to achieve full ash utilization as per CEA 2018–2019 annual report. Ash utilization rate has increased from 55.69% in 2014–2015 to 77.59% as per CEA 2018–2019 annual report. But unresolved area of concern is the utilization of residual or unutilized ash accumulated over the past years (Ujjwal and Kandpal 2000; Yadav and Fulekar 2018). To promote sustainable infrastructure and circular economy, National Institution of Transforming India (NITI) Aayog from last three years has taken up task to revisit existing notifications and formulate policies for effective implementation of 100% ash utilization.

10.1.3 Usage of Ash in Construction Industry and Other Allied Sectors

For the past one and half decade government of India is taking measures to ensure 100 percent utilization of ash but still the same is not achieved due to lack of stringent policies, incentives, technical as well as general awareness among construction fraternity. Ash being pozzolanic material has a huge potential for its utilization in different areas pertaining to construction sector such as (a) manufacturing of cement, (b) back fill material, (c) construction material for roads, bridges, dams, embankments, etc. (d) factory made products like paver block, tiles, fly ash bricks, kerb stone, etc. (e) fly ash-based ceramic products, (f) ingredient for distemper.

10.1.4 Challenges in Ash Utilization in India

The major challenges associated with ash utilization in India are (a) lack of consumers in construction sector due to technical and general awareness (b) lack of business opportunity (c) logistics related problem in remote location (d) low demand in states with high ash generation (e) lack of coordination among different stakeholders like power plants, state government, central government, research organizations and civil society at large. The research-based technologies and practices are need of an hour to maximize ash utilization in India to 100% wherein still a lot of focused and application-based research is missing. Utilization of fly ash-based products shall be made compulsory in construction activities after the sufficient indigenous research data has been evaluated by competent panel of experts and standards/specifications are made by Bureau of Indian Standard or Indian Road Congress for application in construction sector. The way forward to achieve 100% ash utilization to promote durable and environment friendly infrastructure and circular economy in India is strict implementation of policies, promotion of technologies and practices based upon Technology Readiness Level (TRL).

10.2 Classification of Ash

Quality of Indian coal is of low grade wherein ash content is about 30–45% in comparison to imported coals with low ash content of about 10–15%. Depending upon the technologies available for collection including mechanical to electrical precipitators, etc. approximately 80% of the ash from the flue gases is obtained in the form of fly ash and the remaining is collected in the form of bottom ash or pond ash or mound ash. Fly ash is broadly classified on basis of their chemical composition and physical characteristics. The physical and chemical characteristics of fly ash depend upon the quality of coal and coal burning technique (Mukherjee et al. 2008).

10.2.1 Classification on the Basis of Chemical Composition

Fly ashes are mainly rich in silica (amorphous and crystalline), alumina, and iron oxide and also consist of other oxides such as sodium oxide, potassium oxide, magnesium oxide, and sulfate. The total amount of SiO_2, Al_2O_3, and Fe_2O_3 and active lime content (CaO) decides the type of class. Fly ash is therefore classified as siliceous fly ash (class F), if total amount of SiO_2, Al_2O_3, and Fe_2O_3 is more than 70 % and active lime content (CaO) is less than 10%. Calcareous fly ash (class C) constitutes of at least 50% of SiO_2, Al_2O_3, and Fe_2O_3 and active lime content (CaO) is more than 10%. Siliceous fly ash (class F) or low lime fly ash has pozzolanic nature whereas calcareous fly ash (class C) or high lime fly ash has both pozzolanic and hydraulic nature (Bhatta et al. 2019; Bouaissi et al. 2020; Wesche 2005). In case of class F fly ash, the silica content is almost double of alumina content whereas in class of class C fly ash, the content of these two oxides is almost comparable to each other. The amount of iron oxide in class F fly ash is significantly higher than in class C fly ash (Chatterjee 2010). Even pH and calcium/sulfur ratio affects the nature of fly ash (Bhatta et al. 2019).

10.2.2 Classification on the Basis of Physical Characteristics

The performance of cement, mortar, and concrete in terms of rheology, volume stability, strength development, and durability are significantly impacted by the physical behavior of fly ash (Bhatta et al. 2019). The parameters like fineness, particle size, lime reactivity, residue on 45-micron sieve govern the performance criteria. The strength activity index with Portland cement is considered only as an indication of reactivity and should not be used as a measure to predict the compressive strength of concrete containing the fly ash.

10.2.3 Standards and Specification on Fly Ash

Development of standards is always being an ongoing process that largely comprises establishment of a consensus among different interests (Malhotra and Mehta 1996). Table 10.2 represents a compilation of the designations of the relevant national standards and specifications from the different countries of the world. A summary of the main technical features, i.e., chemical and physical requirements of some of the standards as mentioned in Table 10.3 is given in Tables 10.3A and 10.3B.

ASTM C 618 defines fly ash types based upon their chemical composition; Class C and class F. In terms of physical requirements, class C and class F have same limits. Class N fly ash as per ASTM C 618 represents raw or calcined natural pozzolans such as diatomaceous earths, opaline cherts, and shales; tuffs and volcanic ashes complying to the requirements of Table 10.3. IS 3812 cater to the requirements of fly ash for two specific uses: Part 1 covers the use of fly ash as a pozzolana in cement and concrete whereas Part 2 covers the use of fly ash as an admixture for concrete. IS 3812 Part1 classifies the fly ash into two classes based upon their chemical composition, i.e., siliceous fly ash (with reactive lime content less than 10%) and calcareous fly ash (with reactive lime content more than 10%). The European Union Standards (EN 450-1) classify fly ashes based on the Loss of ignition and particle fineness as shown in Table 10.3. The difference in fineness of fly ash from a given lot leads to variations in the water demand and mechanical properties of the resultant concrete (Sear 2001).

Table 10.2 Some of the National standard for fly ash to be use in cement and concrete

Sl	Country	Designation of standard	
1	India	IS 3812 Part1	Pulverized fuel ash—Specification: Part 1; For use as pozzolana in cement, cement mortar and concrete
		IS 3812 Part 2	Pulverized Fuel Ash—Specification Part 2; For Use as Admixture in Cement Mortar and Concrete
2	USA	ASTM C 618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
3	Canada	CSA A3000	Cementitious materials compendium
4	Australia	AS 3582.1	Supplementary cementitious materials—Part 1: Fly ash
5	European Union	EN 450–1	Fly ash for concrete—Part 1: Definition, specifications and conformity criteria
6	Japan	JIS A 6201	Fly Ash for use in Concrete

Table 10.3A Chemical requirements of fly ashes in different countries

Country	USA			India		European		
Chemical Composition (Mass %)	Class			Siliceous	Calcareous	Category		
	N	F	C			A	B	C
Silicon Oxide (SiO_2), min	–	–	–	35.0	25.0	–	–	–
$SiO_2 + Al_2O_3 + Fe_2O_3$, min	70.0	70.0	50.0	70.0	50.0	70.0	70.0	50.0
Sulfur Trioxide (SO_3), max	4.0	5.0	5.0	3.0	3.0	–	–	–
Free Calcium Oxide (CaO), max	–	–	–	–	–	1.50	1.50	1.50
Reactive Calcium Oxide (CaO)	–	–	–	10.0 max	10.0 min	10.0 max	10.0 max	10.0 max
Magnesium Oxide (MgO), max	–	–	–	5.0	5.0	4.0	4.0	4.0
Phosphate (P_2O_5), max	–	–	–			5.0	5.0	5.0
Sodium Oxide Equivalent ($Na_2O + 0.658K_2O$), max	–	–	–	1.50	1.50	–	–	–
Moisture Content, max	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0
Loss on Ignition, max	10.0	6.0	6.0	5.0	5.0	5.0	7.0	9.0
Reactive silica, max	–	–	–	20.0	20.0	25.0	25.0	25.0
Total chlorides, max	–	–	–	0.05	0.05	0.10	0.10	0.10

10.3 Studies Done at Nccbm for Ash Utilization—A Way Forward

To pursue full ash utilization in India, a strict implementation of policies, promotion of technologies, and practices based upon Technology Readiness Level (TRL) is a need of the hour. National Council for Cement & Building Materials (NCCBM) in association with NETRA (NTPC Energy Technology Research Alliance) and other government bodies has carried out research for ash utilization in construction which is discussed hereunder.

10.3.1 Bottom Ash as Replacement of Fine Aggregate

Study has been carried out at NCCBM to replace natural and crushed sand with bottom ash at various percentages for making concrete and study its effect on mechanical and durability properties of concrete. Bottom ash was collected from Vindhyachal thermal power plant of India. Experimental studies were conducted on w/c ratio

Table 10.3B Physical requirements of fly ashes in different countries

Physical parameters	Class			Siliceous	Calcareous	Category	
	N	F	C			N	S
Fineness (m^2/kg)	–	–	–	320.0 min	320.0 min	–	–
Amount retained on a 45 µm sieve (%)	34 max	34 max	34 max	34 max	34 max	40.0 max	12.0 max
Strength Activity Index Ratio to Control @ 7 days	75 min	75 min	75 min	–	–	–	–
Strength Activity Index Ratio to Control @ 28 days	75 min	75 min	75 min	80 min	80 min	75 min	75 min
Strength Activity Index Ratio to Control @ 90 days	–	–	–	–	–	85 min	85 min
Water Requirement (% of Control)	115 max	105 max	105 max	–	–	–	95 max
Soundness by Autoclave Expansion (%)	0.8 max	0.8 max	0.8 max	0.8 max	0.8 max	–	–
Soundness by le chatelier's (mm)	–	–	–	–	–	10 mm	10 mm
Lime reactivity	–	–	–	4.5 min	4.5 min	–	–
Particle Density (kg/m^3)	–	–	–	–	–	± 200 kg/m^3 from declared value	
Initial setting time (max)	–	–	–	–	–	2.0 times the setting time of test cement	

of 0.65 and 0.40. Thirty-Two concrete mixes were prepared using bottom ash as a substitution of natural and crushed sand at various percentages and tested for various mechanical and durability parameters such as compressive and tensile strength, rapid chloride penetrability test, water permeability test, carbonation depth, and chloride depth. Based on fresh concrete properties and strength development studies, 50% replacement of bottom ash is technically feasible. Durability properties of concrete mixes at 50% replacement of natural and crushed sand with bottom ash are comparable with the control mixes. Based on the findings by the authors (Ojha et al. 2020a), the Indian Standard IS: 383-2016 is proposed for revision which will enhance the use of bottom ash as fine aggregate in construction. Research indicated that specific gravity of bottom ash is lower in comparison to conventional fine aggregate and fineness modulus is also on lower side. Therefore, there is an urgent need for development of methodology and concrete mix design guidelines when bottom ash replacement is to be done in different percentage of conventional fine aggregate.

10.3.2 Flyash Concrete—A Cost Effective Solution

Research has been conducted by NCCBM on fly ash concrete as well as on the use of PPC in M40 grade concrete and above for utilization in prestressed concrete and cement concrete roads. Studies indicated that except for the slow gain in strength at early ages, the mechanical properties and durability of the fly ash concrete were superior to the normal concrete (Arora and Singh 2016). Based on the durability and corrosion studies, it can be concluded that PPC is more durable than OPC in coastal environment/aggressive environment owing to high resistance to chloride ion penetration in PPC. Results of the accelerated carbonation test indicate that carbonation induced corrosion is more in PPC made concrete as compared to OPC and OPC is more durable as compared to PPC in areas other than coastal environment. This increase in carbonation in case of PPC made concrete may enhance the rate of corrosion and precautions that needs to be taken are related to late strength development, enhanced curing regime, and additional cover to cater carbonation induced corrosion (Arora and Singh 2017). The further study is required to investigate high performance fly ash concrete using multifunctional admixtures (plasticizer and accelerator) for pavements and dams in India.

10.3.3 Fly Ash and Slag-Based Geopolymer Concrete

Comprehensive studies were carried out at NCCBM to optimize ratios of SiO_2/Al_2O_3, SiO_2/Na_2O for the production of geopolymer concrete. Findings of research show that with minor modifications in test, formulation and usage methodology, plain alkali activated precast products can be used as a substitute to normal concrete products (Yadav et al. 2020). The study highlighted that cost can be brought to comparable

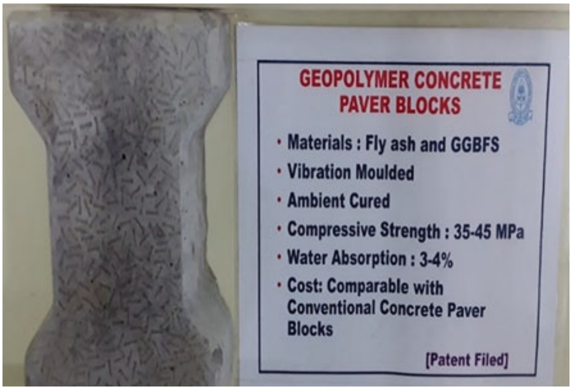

Fig. 10.2 Flyash based geopolymer concrete paver block

Fig. 10.3 Flyash based geopolymer concrete block road stretch

to conventional concrete by resorting to commercial grade of chemicals and maximizing usage of relatively cheaper materials like fly ash. A trial stretch was cast with plain alkali activated precast paver blocks, as shown in Figs. 10.2 and 10.3. Findings of the study contributed in the development of Indian standard on precast geopolymer concrete products. Since flyash-based geopolymer concrete is a low calcium system, there is a need to develop admixtures which can improve early strength development even at ambient conditions. Further studies are also needed to develop design parameters for geopolymer concrete for its structural applications.

10.3.4 Sintered Fly Ash Light Weight Aggregate for Structural Concrete

Research was conducted to evaluate the potential of sintered fly ash coarse aggregate in masonry, structural, and light weight blocks (both hollow and solid). Based on the detailed study, it can be concluded that both the fractions of lightweight aggregate

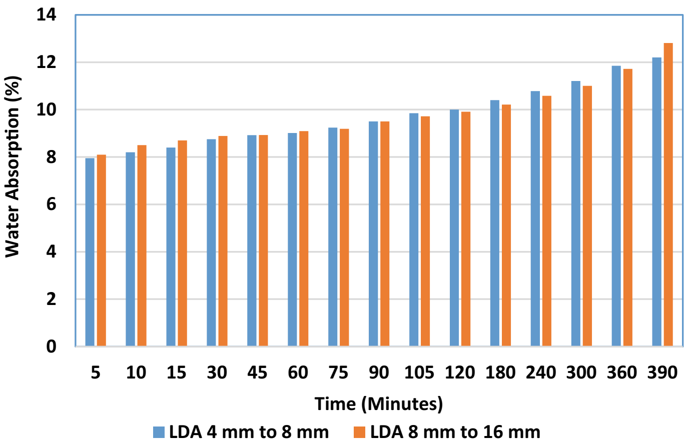

Fig. 10.4 Water absorption at different interval for fraction 4–8 mm LDA and 8–16 mm LDA (Soundaram et al. 2020)

can be used in concrete masonry units, production of hollow and solid lightweight concrete blocks. Results of abrasion, crushing, and impact values indicate that lightweight aggregate shall not be used for concrete to be used in wearing surfaces. Study on mechanical and durability properties SLC indicate that concrete made with lightweight coarse aggregate can be used as structural concrete. However, various structural design codal provisions need to be established for structural lightweight concrete since parameters such as flexural strength and modulus of elasticity values are lower than that of normal weight concrete for same compressive strength. Codal provision such as limit on cement content, free water-cement ratio, and concrete cover to the reinforcement shall be further strict than that of normal weight aggregate concrete to ensure similar level of durability in the same exposure conditions. The findings of the study have resulted in the development of new Bureau of Indian standard IS: 9142 (Part-2)-2018 on sintered flyash lightweight coarse aggregate in structural applications (Ojha et al. 2021). Further studies are needed to enhance the physical properties of sintered flyash aggregate and to explore its application in reinforced and prestressed concrete (Fig. 10.4).

10.3.5 Controlled Low Strength Material for Backfilling

Detailed study was conducted on fresh, hardened, and water penetration property of Controlled Low Strength Material (CLSM) at NCCBM (Ojha et al. 2020b). Some of the mix design trails conducted for CLSM are mentioned in Table 10.4. Test results corresponding to compressive strength and density are given in Table 10.5. Study indicated that due to the presence of fine materials and fillers in place of coarse aggregate there was no issues in fresh behavior of CLSM. Findings highlighted that

Table 10.4 Trials conducted for CLSM

Sl. no	Water content (Kg/m^3)	Cement content (Kg/m^3)	Fly ash content (Kg/m^3)	Fine aggregate content (Kg/m^3)
Mix-1	250	30	460	1364
Mix-2	250	50	460	1347
Mix-3	250	70	460	1330
Mix-4	290	30	800	839
Mix-5	304	50	800	786
Mix-6	355	50	1000	405
Mix-7	375	30	1200	122

Table 10.5 CLSM test results

Sl. No	Slump of concrete (mm)	7-Day cube comp. strength (N/mm^2)	28-Day cube comp. strength (N/mm^2)	CLSM density (Kg/m^3)
Mix-1	180	0.80	1.45	2122
Mix-2	170	1.20	2.99	2126
Mix-3	170	1.40	3.62	2132
Mix-4	165	0.85	1.77	1976
Mix-5	195	1.82	3.68	1954
Mix-6	185	1.65	3.09	1832
Mix-7	180	0.66	1.47	1736

coefficient of permeability of CLSM (1×10^{-8} cm/s) is lower than clay (1×10^{-7} cm/s). The fly ash used in the study of CLSM conforms to IS: 3812 (Part 2). As the fly ash content used in the study is as high as 1200 kg/m^3, it has a great potential to be used in CLSM as landfill and backfill material.

10.3.6 Pond Ash—Clay Fired Bricks

Prashant and Dwivedi (2013) carried out the comparison of bricks with varying percentage of pond ash substitution with clay bricks. Findings of the study indicated that substitution of pond ash with clay bricks beyond 20% was not technically feasible as it lead to issues related to dimension exceeding tolerance limit, significant increase in water absorption, and decrease in compressive strength. In field of bricks and blocks, a new standard on fly ash cement bricks (IS 16720) has been already formulated. Hence, there is huge potential for application of pond ash clay fired bricks. Application of pond ash in non-structural elements like kerb stone, paver blocks needs to be explored.

10.4 Conclusion and Need of Further Research

With the advancement in the techniques and various government policies, ash generated from thermal power plants has acquired a status of value-added materials. The use of ash in terms of bottom ash as a fine aggregate, blended cement or fly ash concrete, low calcium or high calcium geopolymer concrete, sintered fly ash light weight aggregate for structural concrete, controlled low strength material for backfilling, and pond ash for brick production has shown promising performance. Currently IS: 6491-1972 method for sampling fly ash is about 50 years old. During this period there has been significant changes with respect to technology of coal firing system, conveyance, and collection system of ash. Present standard does not include sampling method for bottom ash. In view of this there is an urgent need for revision of Indian standard pertaining to method of sampling fly ash. Further research is needed in different areas like (a) methodology and concrete mix design guidelines for usage of bottom ash as fine aggregate (b) development of multifunctional admixtures (plasticizer and accelerator) for production high performance fly ash concrete for pavements and dams (c) development of admixtures which can improve early strength development even at ambient conditions in low calcium-based geopolymer concrete (d) development of design parameters for low calcium geopolymer concrete for its structural applications (e) development of technology or methodology for improvement in the physical properties of sintered fly ash aggregate and to explore its application in reinforced and prestressed concrete.

References

ACI 232.2R, Use of fly ash in concrete

AS 3582.1, Supplementary cementitious materials—Part 1: fly ash

Anon (2019) Executive summary on the power sector. Central Electricity Authority. Available at the http://cea.nic.in/reports/monthly/executivesummary/2019/exe_summary-10.pdf. Accessed 21 Sept 2020

Arora VV, Singh B (2017) Use of fly ash concrete and recycled concrete aggregates-a cost effective solution and durable option for construction of concrete roads. Indian Concr J 91(1)

Arora VV, Singh B (2016) Durability studies on prestressed concrete made with portland pozzolana cement. Indian Concr J 90(8)

Bhatta A, Priyadarshinia S, Mohanakrishnana AA, Abria A, Sattlera M, Techapaphawitc S (2019) Physical, chemical, and geotechnical properties of coal fly ash: a global review. Constr Mater. https://doi.org/10.1016/j.cscm.2019.e00263

Bouaissi A, Li LY, Abdullah MMAB, Ahmad R, Razak RA, Yahya Z (2020) Fly ash as a cementitious material for concrete. Zero Energy Build-New Approaches Technol. http://dx.doi.org/https://doi.org/10.5772/intechopen.90466

CEA: Central Electricity Authority Report (2018–2019) Available online at: http://cea.nic.in/reports/others/thermal/tcd/flyash_201819.pdf. Accessed 05 Apr 2020

Chatterjee KA (2010) Indian Fly ashes, their characteristics, and potential for mechano-chemical activation for enhanced usability. In: Second international conference on sustainable construction materials and technologies

CSA A3000, Cementitious materials compendium

EN 450–1, Fly ash for concrete—Part 1: definition, specifications and conformity criteria
JIS A 6201, Fly Ash for use in Concrete
Wesche K (2005) Fly ash in concrete. Chapman & Hall, Properties and performance, London, UK
Malhotra VM, Mehta PK (1996) Pozzolanic and cementitious materials. CRC Press
MOEF (1999) Gazette notification for ministry of environment and forests, vol 563. Ministry of Environment and Forests, New Delhi
Mukherjee AB, Zevenhoven R, Bhattacharya P, Sajwan KS, Kikuchi R (2008) Mercury flow via coal and coal utilization by-products: a global perspective. Resour Conserv Recycl 52(4):571–559
Ojha PN, Singh B, Behera AK (2021) Sintered fly ash light weight aggregate—its properties and performance in structural concrete. Indian Concr J
Ojha PN, Kumar S, Singh B, Mohapatra BN (2020a) Pervious concrete, plastic concrete and CLSM-a special application concrete. J Build Mater Struct
Ojha PN, Trivedi A, Singh B, Singh A (2020b) Evaluation of mechanical and durability properties of concrete made with indian bottom ash as replacement of fine aggregate. Asian Concr Fed J
Prashant GS, Dwivedi AK (2013) Technical properties of pond ash—clay fired bricks—an experimental study. Am J Eng Res 02(09):110–117
Sear LKA (2001) The properties and use of coal fly ash. Thomas Telford Ltd.
Soundaram R, Arora S, Trivedi V (2020) Coal-based power norms—where do we stand today? Centre for science and environment. Delhi
Ujjwal B, Kandpal TC (2000) Potential of fly ash utilisation in India. Energy 27(1):151–166
Yadav KV, Fulekar MH (2018) The current scenario of thermal power plants and fly ash: production and utilization with a focus in India. Int J Adv Eng Res Dev 05(04)
Yadav L, Trivedi A, Arora VV, Mohapatra BN (2020) Case study on field trials of developed geopolymer (Slag and Fly Ash Based) precast concrete paver blocks. Indian Concr J