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XRD and SEM analysis of fly ash obtained from TPPs of Raipur district of Chhattisgarh

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Abstract

This paper deals with the study of fly ash samples with respect to its physical, chemical and structural properties collected from distinct sites of Raipur district of Chhattisgarh state in India. XRD diffractogram for the original fly ash confirms the fly ash is mainly an amorphous material with the presents of crystalline phase of quartz. Fly ashes samples consist of mostly glassy, hollow, spherical particles, which are cenospheres (thin-walled hollow spheres); the micro structure appearance of the original fly ash is well agreed. Equal amounts of Al_2O_3, Fe_2O_3, MnO, TiO_2 were found in both the samples which are good fit for construction application. SEM images revealed the amorphous nature of the fly ash.

Keywords: XRD; Morphology; Thermal Power Plants; Chhattisgarh; Construction Application; Waste Management

1. Introduction

The production and utilization of enormous amount of energy leads to the paths for novel findings in every aspect of human life. But alongside the merits of generation of such large energy for urbanization and new scientific technologies there were some demerits as well. The combustion of fossils like coal gives rise to incredible increment of air pollution, the unloading of solid waste like fly ash nearby agricultural land gives birth to land or soil pollution and the inclusion of its hazardous component both through air and land in water pollutes the water.

The waste generated from industries are complex characteristics and composition, hence it is necessary to safely dispose the wastes otherwise it will have a negative impact on environment and social life, which will ultimately disturb the ecological system. Proper treatment has to be made before the disposal and storage of the industrial wastes, otherwise it makes the soil and water contaminate.

The micro sized fly ash mainly consists of silica, alumina and iron. The fly ash particles are generally spherical in size, which makes them easy to blend and to flow, to make a suitable mixture. The capillarity is one of the best properties for fly ashes to add as admixture for concrete. The fly ash contains amorphous and crystalline nature of minerals.

Coal based thermal power stations are responsible for one of the largest industrial waste streams in India—coal ash. As fugitive emissions in the dry form and as leakage of ash slurry from ash ponds, coal ash is a major environmental and health concern today. It has been under the regulatory scanner for more than two decades. However, attempts to ensure its 100 percent utilization are yet to bear fruit. Therefore, along with the current emphasis on meeting emissions standards, ash utilization also must be made a priority issue.

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Fly ashes are generated from combustion of coal at thermal power generating plants. The production of fly ash in rapidly increased due to vastly growing industrialization. In the power plants before the combustion of coal it is been grind and converted into fine powder to utilize most from it. The safe disposal and waste management is the most important threat in the whole process of fly ash production. In order to maintain the ecological balance of the nature we need to properly dispose the toxic and complex characterized waste produced from various industries so that it will not impose any sort of harmful effect on our environment and social life [1-5].

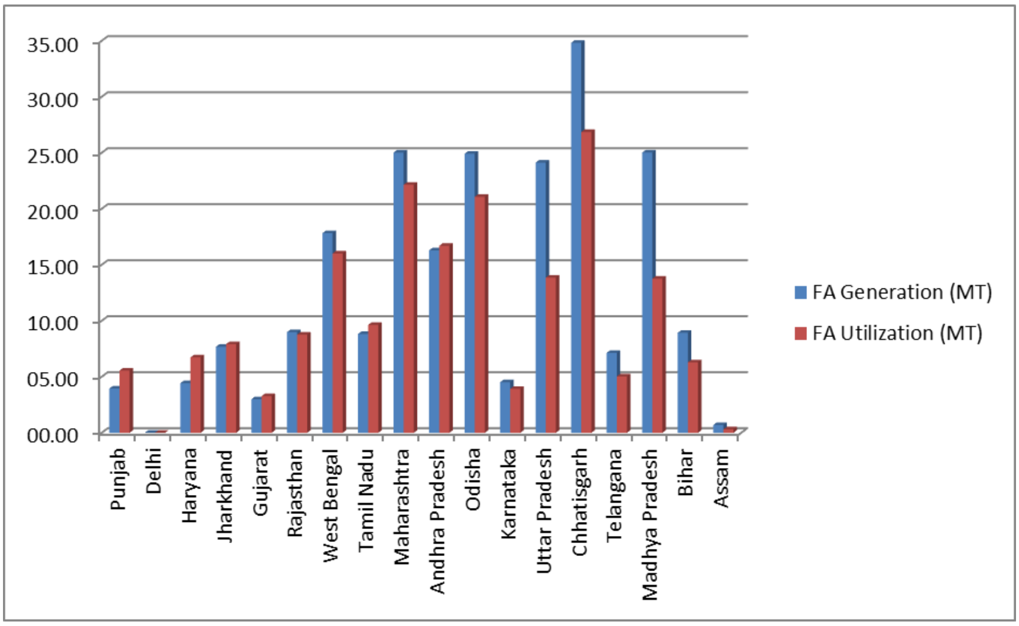

Figure 1 State wise Fly Ash generation and its utilization during year 2019-20

Now, we will look after a comparison of 18 Indian states as per the report during the year 2019-20 of their power plant installation capacity, fly ash generation and fly ash utilization in million tons.

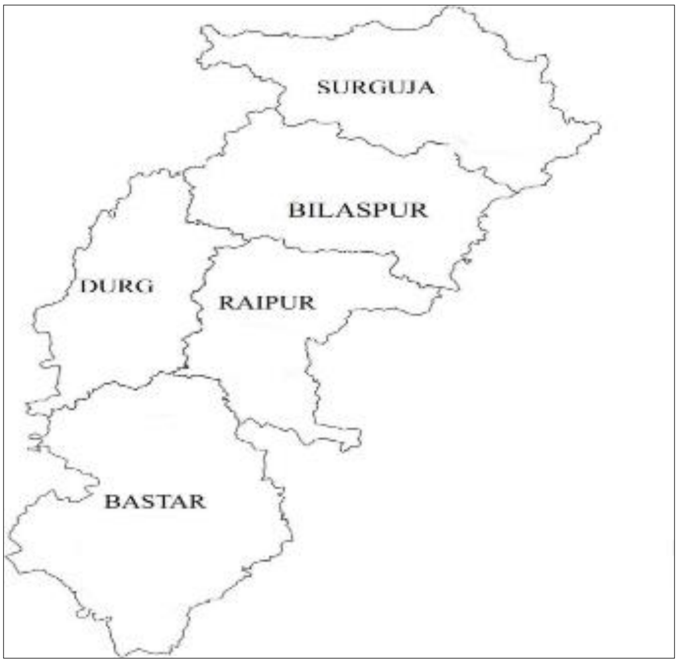

Figure 2 Chhattisgarh State

In the state of Chhattisgarh there are some major thermal power plants are situated at Korba, Bilaspur, Raipur and Durg Divisions. Thermal power plants of Korba district which generates about 24000 metric tons per day or 8.7 million tons of fly ash annually that is approximately 9/10th part of the total fly ash produced in the Chhattisgarh State. The figure 2 shows the divisional breakups of the Chhattisgarh state.

Utilization of Fly ash during the last 30 years, extensive research has been carried out to utilize the fly ash in various sectors. Broadly, fly ash utilization programmes can be viewed from two angles, i.e. mitigating environmental effects and addressing disposal problems (low value–high volume utilization). Followings are some of the potential areas of use of fly ash [6-8] (approximately in order of decreasing importance):

- Concrete production, as a substitute material for Portland cement and sand
- Embankments and other structural fills (usually for road construction)
- Grout and Flowable fill production
- Waste stabilization and solidification
- Cement clinkers production - (as a substitute material for clay)
- Mine reclamation
- Stabilization of soft soils
- Road sub-base construction [9-10]
- As Aggregate substitute material (e.g. for brick production)
- Mineral filler in asphaltic concrete [11]
- Agricultural uses: soil amendment, fertilizer, cattle feeders, soil stabilization in stock feed yards, and agricultural stakes [12-19]
- Loose application on rivers to melt ice [20-22]
- Loose application on roads and parking lots for ice control [23]

Other applications include cosmetics, toothpaste, kitchen counter tops, floor and ceiling tiles, bowling balls, flotation devices, stucco, utensils, tool handles, picture frames, auto bodies and boat hulls, cellular concrete, geopolymers, roofing tiles, roofing granules, decking, fireplace mantles, cinder block, PVC pipe, Structural Insulated Panels, house siding and trim, running tracks, blasting grit, recycled plastic lumber, utility poles and crossarms, railway sleepers, highway sound barriers, marine pilings, doors, window frames, scaffolding, sign posts, crypts, columns, railroad ties, vinyl flooring, paving stones, shower stalls, garage doors, park benches, landscape timbers, planters, pallet blocks, molding, mail boxes, artificial reef, binding agent, paints and under coatings, metal castings, and filler in wood and plastic products [24-30]

Table 1 Mode of fly ash utilization [31]

Sl. No.	**Mode of Utilization**	**Quantity of fly ash utilized in the mode of utilization**	
		Million – Ton	Percentage
01	Cement	57.8847	25.60
02	Mine Filling	10.6152	4.69
03	Bricks & Tiles	21.3888	9.46
04	Reclamation of low-lying area	35.0600	15.50
05	Ash Dyke Raising	22.1688	9.80
06	Roads & Flyovers	20.9667	9.27
07	Agriculture	0.1415	0.06
08	Concrete	1.6660	0.74
09	Hydro Power Sector	0.0000	0.00
10	Others	17.9136	7.92
11	Unutilized Ash	38.3287	16.96
	Total	226.1339	100.00

2. Materials and Methodology

This paper dealt with the methodology used for the sample fly ash collection and its characterization. The sample fly ash in my research work is collected from the shallow area of Shri Bajrang Power & Ispat Ltd. and Jagdamba Power and Alloys Ltd. both located at Raipur. After the collection of fly ash sample, the sample is taken into for several characterizations in different stages. Initially the samples are taken for sieving then the samples are distributed for XRD and SEM Analysis. The paper includes the study of fly ash samples with respect to its physical, chemical and structural properties. The chemical composition of the sample has been obtained with the help an X-ray fluorescence (XRF) setup (model Rigaku RIX 3000).

Figure 3 PANalytical 3 kW X'pert XRD

Figure 4 Scanning Electron Microscope (SEM – 3069)

Figure 5 Sieve of 75 microns for sieving of test samples

2.1. Physical parameter analysis

A laser particle size analyzer, Huriba Capa-7000 Particle Analyzer, have been used to study the particle size distribution of the fly ash sample.

Table 2 Chemical Compositions of the fly ash samples from both sites

Compound	Fly Ash Content (in %) from Shri Bajrang Power & Ispat Ltd.	Fly Ash Content (in %) from Jagdamba Power and Alloys Ltd.
SiO_2	26.4	52.11
Al_2O_3	9.25	23.59
Fe_2O_3	30.13	7.39
TiO_2	3.07	0.88
CaO	21.6	2.61
Na_2O	-	0.78
K_2O	2.58	0.42
P_2O_5	0.67	0.80
SO_3	1.3	1.31
MnO	0.27	0.49
LOI	2.62	4.55

2.2. Structural and morphological analysis

Figure 6 presents XRD diffractogram for the original fly ash. It can be observed that the fly ash is mainly an amorphous material with the presents of crystalline phase of quartz (SiO_2) at 20.8 and15.1 2θ (degree), and mullite ($3Al_2O_3.2SiO_2$) at 17.4 and 35.1 2θ (degree).

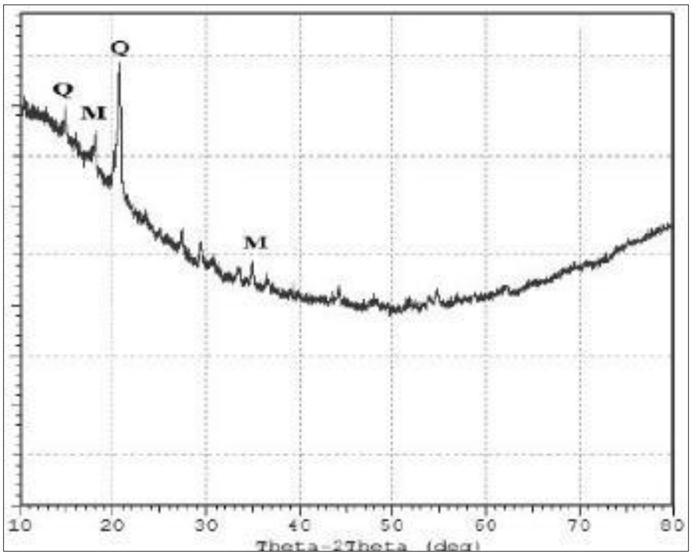

Figure 6 X-ray diffraction pattern of the original fly ash. Q = quartz, M = mullite.

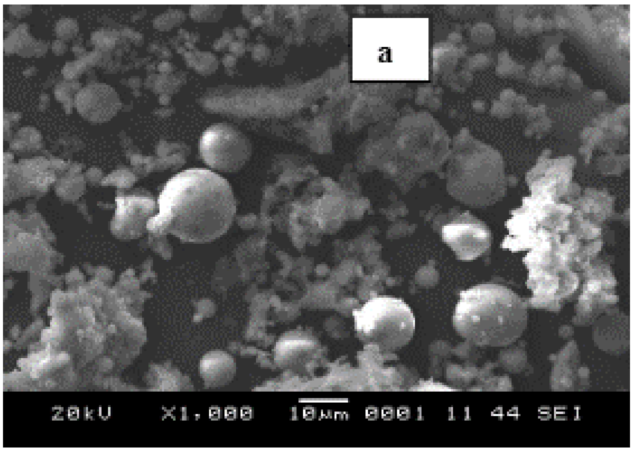

Figure 7 Microstructure with SEM of Shri Bajrang Power & Ispat Ltd. Raipur

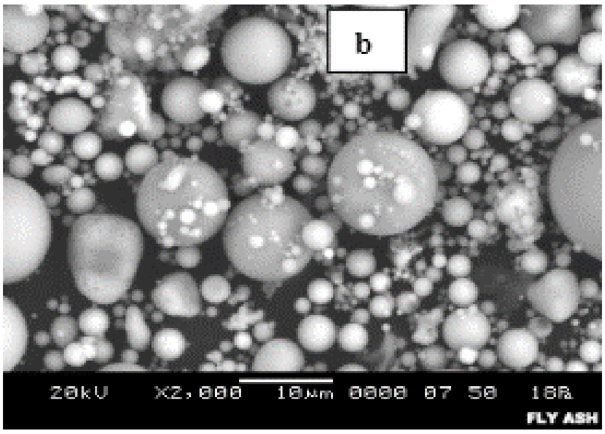

Figure 8 Microstructure with SEM of Jagdamba Power and Alloys Ltd. Raipur

Figure 7 shows the SEM micrograph of the original fly ash of Shri Bajrang Power & Ispat Ltd. whereas figure 8 of Jagdamba Power and Alloys Ltd. Raipur. Both fly ashes consist of mostly glassy, hollow, spherical particles, which are cenospheres (thin walled hollow spheres); the micro structure appearance of the original fly ash is well agreed.

Although fly ash particles are essentially the same, variations do occur in shape (rounded to angular) with some crystals of mullite and iron. Furthermore, surface texture appears to be smooth and dense to highly porous and present or absence of surface coatings likes magnetite. The mineralogical and chemical composition of fly ash depends on the source of the coal and design of the power stations.

3. Result and Discussion

Millions of tons of fly ash produced each year due to the massive consumption of coal. The industry is facing problem to develop efficient and economical technique recycle these materials. Recycling of fly ash will conserve the natural raw materials and abridge the disposal cost. It will also create new revenues and business opportunities while protecting the environment. The chemical compositions of the sample have been examined according to ASTM C618. Different sources of fly ash may result in different chemical composition. The fly ash is mainly an amorphous material with the presents of crystalline phase of quartz and mullite. Fly ash consists of mostly glassy, hollow and spherical particles. Study on fly ash can be furthered and expanded to many other applications in the near future.

The material used in this work was coal fly ash collected from two thermal power plant and was processed. The material was characterized by measuring surface area, XRD and SEM characteristics and XRF analysis. The following observations can be drawn from these measurements:

Calcined fly ash samples were used for XRD measurements. XRD patterns of the raw fly ash, water-washed fly ash and acid-washed fly ash samples did not show any remarkable difference from one to another. This indicates that the treatment with water or acid did not alter the chemical phases present in the original fly ash.

XRD measurements showed that the loss on ignition was maximum in raw fly ash in comparison to the water washed fly ash and the acid washed fly ash samples. The amount of silica in water treated ash was higher in comparison to acid treated and raw ash. More or less equal amounts of Al_2O_3, Fe_2O_3, MnO, TiO_2 were found in both the samples.

SEM images revealed the amorphous nature of the fly ash, with particle agglomerates and distinct difference in the morphology of the samples. The fly ash showed fibrous and porous structure with uneven topography. Treatment of the fly ash with water or acid exposed a compact structure of the fly ash particles. The fly ash samples having different treatments showed a variety of pores with a heterogeneous distribution of pore diameters.

The following works may be carried out in future:

- Investigating the influence of acid and alkali (of different concentrations) treatments on the adsorptive properties of fly ash from Raipur district.
- Determination of surface charge, surface acidity, effect of acid and alkali treatment and nanopore properties of fly ash.
- Performing adsorption studies with other metal cations, other inorganic non-metallic and organic pollutants.
- Investigating competitive adsorption of two or more adsorbates.
- Using the most favorable conditions as obtained from the batch adsorption processes, column studies are to be undertaken for evaluating the practical utility of the adsorption process in industrial scale.
- To study desorption of the pollutants from the fly ash adsorbent and hence to suggest suitable methods for regenerating the adsorbents for further use.
- More comprehensive study of the thermodynamics of adsorption with respect to the fly ash adsorbents may be considered.
- The nano structured fly ash may be studied for adsorption properties.
- To evaluate different mathematical models to understand the adsorbent-adsorbate process more clearly.

4. Conclusion

The study on coal fly ash of Chhattisgarh state highlights its potential as a valuable resource in various applications, particularly in the construction industry. Despite the chemical composition remaining largely unchanged through different treatment methods, significant alterations in physical properties were observed. The increased silica content and modified particle morphology following water and acid treatments suggest that fly ash can be optimized for enhanced performance in cement and concrete production.

Recycling fly ash not only conserves natural resources but also reduces waste disposal costs, offering economic benefits and new business opportunities. As the industry faces the challenges of managing coal combustion byproducts, further research into the efficient use of fly ash will be crucial. By leveraging its unique properties, we can promote sustainable practices that protect the environment and contribute to a circular economy. This study serves as a foundation for future investigations aimed at unlocking the full potential of fly ash and advancing its applications in material science.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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