Original Research Article

Characterization of thermal power plant coal combustion residues

Giriraj S. Mandloi[1], Anam Khan[1], Ravi Patidar[1], Avinash Singh[1], Alka Mishra[2*], Asokan Pappu[2]

[1]Research Scholar, [2]Scientist and Senior Principal Scientist, Department of construction Material Division, Advance Material and Process Research Institute Bhopal, Madhya Pradesh, INDIA.
Email: alkamishra1@gmail.com

Abstract

India produces about 950 million tons of Industrial waste annually. Fly ash alone account to about 240 million tons. Disposal of such huge waste is a challenge to the country to protect our mother land and human health. An Industrial coal combustion residue is used for the development of wood substitute for building application, so that consumption of forest in building construction can be minimized. In the present research article, physical properties, chemical composition and other properties of fly ash waste combustion residue of thermal power plant, have been studied.
Key Words: Industrial coal combustion residue, fly ash, thermal power plant, particulates reinforced materials.

[*]Address for Correspondence:
Dr. Alka Mishra, Scientist, Department of ACM, CSIR-AMPRI, Hoshangabad Road, Near Habibganj Naka, Sanket Nagar, Habib Ganj, Bhopal, Madhya Pradesh -462024, INDIA.
Email: alkamishra1@gmail.com

Access this article online	
Quick Response Code:	Website: www.statperson.com
	Accessed Date: 26 March 2018

INTRODUCTION

Coal is the most important and abundant fossil fuel in India. It accounts for 55% of the country's energy need. The country's industrial heritage was built upon indigenous coal. Commercial primary energy consumption in India has grown by about 700% in the last four decades. In India, mostly two types of ashes are produced namely, fly ash and bottom ash. Fly ash is a by-product from the combustion of pulverized coal in thermal power stations, and is removed by mechanical collectors or electrostatic precipitators as a fine particulate residue from the combustion gases. Fly ash can further be classified into two types, Type F and Type C. Type F ash is produced from bituminous coal, has low lime content, and possesses little cementitious value by itself[1]. Type C fly ash is produced from sub-bituminous or lignite coals, has higher lime content and possesses some cementitious qualities of its own. Bottom ash is the coarser portion that is collected at the boiler bottom. Wet system of disposal is followed by most of the thermal power stations in India[2-16]. Recently, attempts have also been made to utilize fly ash in bulk for wasteland development[17,18]. Coal India limited and its subsidiaries accounted for 538.75 million tonnes (including Gare-Palma block) during 2015-16 as against a production of 494.23 million tonnes in 2014-15 showing a growth of 9%. Coal based power plants, cement plants, captive power plants, sponge iron plants, industrial consumers and coal traders are importing non-coking coal. All the coal based power stations put together generate around 90 million tones of fly-ash per annum. The Fly Ash Mission of TIFAC has made several useful recommendations for utilization of fly-ash in the manufacture of cement, bricks, pavement materials, floor tiles, wall panels etc., and in agriculture, road construction, land-filling and back-filling of mines. Armed with the findings of the national laboratories that fly ash is superior in strength and durability as compared to conventional products, the Ministry of Power is taking steps to make the use of fly ash products mandatory in road and bridge construction, and construction of Government buildings as is being done in the developed countries and to provide financial incentives initially to supplement the market mechanism for taking up production and promotion of fly ash products (Ministry of Power 2015). Table-1 shows the status of world energy at end 2016-17. During the process of (coal) burning, according to an estimate, 112 million tonnes of fly ash is presently generated per annum in India alone[1,2], whose level is to be further raised with the installation of more new thermal power plants by 2020[3]. Many experiments and studies on the outcome and potentiality of fly-ash as a modification in agricultural applications have been stepped frontward by various agencies, research institutes at dispersed locations all over the world. In this paper, we described about consumption of fly-ash as coal combustion residues and physicochemical characterized.

Table 1: Status of India energy at the end 2011 to 2016-17 Import up to May, 2016 (Million tones)

Coal	2011-12	2012-13	2013-14	2014-15	2015-16(Prov.)	2016-17*
	31.8	35.56	36.87	43.72	43.5	5.83
	71.05	110.23	129.99	174.07	156.38	29.26
	102.85	145.79	166.86	217.78	199.88	35.09
	2.37	3.08	4.17	3.29	--	0.8

Fly ash physical, chemical, thermal gravimetric analysis and mineralogical properties combined with its large scale production make fly ash an attractive raw material for various applications.

MATERIAL AND METHODS

The sample of fly ash from Electro Static Precipitator of Satpura Thermal Power Station, Sarni, Central India, were collected. The work was carried out at Advanced Materials and Processes Research Institute (CSIR-AMPRI), formally it's known as a Regional Research Laboratory Bhopal, India. The samples (SFA-1and SFA-2) were oven dried separately, well ground, sieved through 2mm size sieve and stored in glass container.

Characterization: The thermal gravimetric analysis of fly ash, ware done by Mettler Toledo analyzer (Model TGA/DSC[1], STAR[e] System SW 9.20., USA), using nitrogen atmosphere (40-50 cm^3/min), with the experimental set up consisted of a heating ramp from 25 to 1100°C at 10°C min^{-1} and the mineralogical and morphological studies were carried out by X-Ray Diffract meter-(PW-1710, Philips, Netherlands, with Quasar software packages). The samples were scanned in the range of 5–70°2θ. The microstructure characteristics of all powders were analyzed by scanning electron microscope Model JOEL-JSM-5600, Japan. Before recording the Fourier transform Spectroscopy (FT-IR) spectra all these powders was dried at 150°C, FT-IR spectra was recorded from 4000 to 400 cm^{-1} (100 scans) on samples in KBr pellets using Shimadzu IR-Prestige-21 analysis facilities. The chemical composition of fly ash (FA) was determined by standard wet chemical analysis method of chemical analysis.

RESULTS AND DISCUSSION

Chemical characterization: The results of chemical analysis of fly ash samples appear very similar to the chemical analysis of fly ash as described elsewhere[1]. The fly ash is a fine particulate waste material produced by crushed coal-based thermal power station, is an environmental pollutant, has a potential to be a resource material[2]. It is nowadays used in cement, concrete and other cement based applications in India[3,4]. The chemical properties of fly ash have been studied by many researchers[5,6]. Various chemical parameters such as hardness have been determined in the three replicate for the collected samples and are listed in the tables below.

Table 2: Chemical characteristics obtained for samples of fly ash (SFA-1and2) collected from various sites in Sarni (M.P.).

Sample	Replicates	Total Hardness (mg/L)	Ca Hardness as ($CaCO_3$) (mg/L)	Mg Harness as ($CaCO_3$) (mg/L)	Chloride (mg/L)	Ca (mg/L)	Mg (mg/L)
	R-1	2	1.35	1.61	9.05	0.5	19.44
	R-2	1.99	1.34	1.62	9.04	0.4	19.43
	R-3	1.98	1.36	1.59	9.06	0.49	19.45
	Mean	1.99	1.35	1.60666667	9.05	0.46333333	19.44
	SD	0.01	0.01	0.01527525	0.01	0.05507571	0.01
	R-1	2.77	2.15	2.24	2.24	0.8	27.21
	R-2	2.76	2.16	2.23	2.23	0.79	27.23
	R-3	2.78	2.16	2.25	2.25	0.81	27.24
	Mean	2.035	2.15666667	2.24	2.24	0.8	27.2266667
	SD	0.01	0.0057735	0.01		0.01	0.01527525

The terms Calcium, Magnesium, and Chloride refer to the extractable ions (7,8). The total hardness determined lies between 2.0-3.0 mg/l, which shows the presence of very less dissolved salts in the samples. The values of calcium and magnesium were in range of 1.35-2.15 mg/l and 1.61-2.24 mg/l respectively. The values of chloride lie between 9.05 and 14.49 mg/l which are well within limits. The values of magnesium are 19.44 and 27.21mg/l.

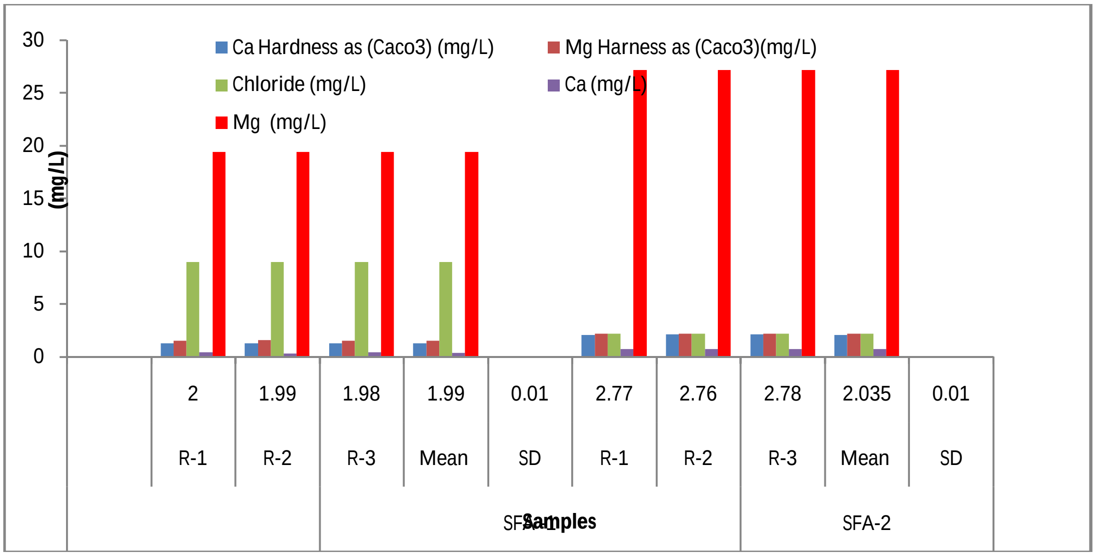

Figure 1: Graphical representation of variation in Total Hardness, Calcium and Magnesium of Fly ash samples (SFA-1and2) collected from various sites in Sarni (M.P.).

However samples had low total hardness of SFA-1 and SFA-2 lying between 2.00 and 2.77 respectively indicating the presence of dissolved Calcium and Magnesium in high amounts shown in Table- 2.3. The results were also confirmed with earlier publication[9].

Physical Characterization: Physical characteristics such as bulk density, porosity, water holding capacity, specific gravity, pH, conductivity of fly ash samples were determined. Characteristics such as electrical conductivity and pH were obtained from water digested samples. The results are presented in the following table.

Table 3: Physical characteristics (Bulk Density, Porosity, Water holding capacity, Specific gravity) of the samples of fly ash collected from Sarni, Betul, Madhya Pradesh

Sample	Entry	Bulk Density (g/cm^3)	Specific gravity	Porosity (%)	Water holding Capacity (%)	pH	Electrical Conductivity mS/cm
	R-1	1.20	2.09	42.41	32.55	6.69	0.18
	R-2	1.18	2.06	51.43	30.43	6.86	0.18
	R-3	1.05	2.14	56.92	34.54	6.93	0. 18
	Mean	1.14	2.09	50.25	32.50	6.83	0.18
	SD	0.08	0.04	7.32	2.055	0.12	0.00
	R-1	1.16	2.16	39.11	28.88	7.17	0.38
	R-2	1.15	2.37	43.65	27.08	7.24	0.38
	R-3	1.13	2.14	43.81	35.55	7.35	0.38
	Mean	1.14	2.22	42.19	30.50	7.25	0.38
	SD	0.01	0.12	2.67	4.46	0.08	0.00

From the obtained data, it can be observed that fly ash samples possess low to medium bulk density while specific gravity lies in the range 1.49-1.70. A Higher porosity and water holding capacity of sample-1 indicates relatively larger pore size as compared to sample-2. The Results reveal that pH of fly ash samples was almost neutral while electrical conductivity was low indicating less free ions in the sample.

Morphological Characterisation: Scanning Electron Microscopy (SEM) image analyses were done for fly ash samples (SFA-1and2), collected from Satpura Thermal Power Station, Sarni (M.P.). The fly ash waste powder samples (SFA-1and2), it can be noticed from micrographs that the particles fly ash having a fine grained material consisting of spherical, ranging in size between 05 to 10 micron shown in Figure-3.4[7,8].

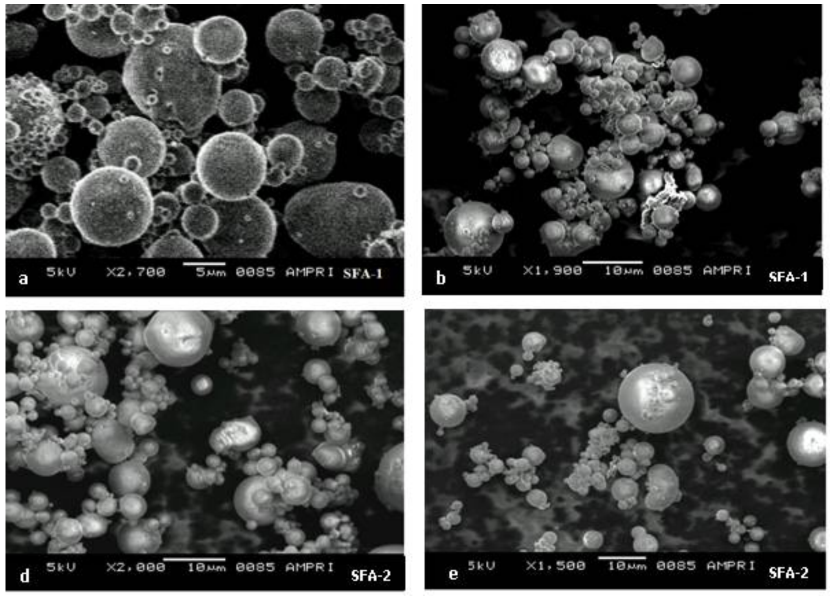

Figure 2: Representative Scanning Electron Microscopy (SEM) images of Fly Ash (SFA-1a– b), and (SFA-2c– d) from various sites in Sarni (M.P.).

ASTM specifications, fly ash is described as a fine powder of mainly spherical glass particles having siliceous and aluminous materials properties, which consist essentially of reactive SiO_2 and Al_2O_3 [9,10].

Mineralogical Characterisation: X-Ray Diffraction analysis was performed for fly ash (SFA-1andSFA-2) waste samples. Based on the diffractogram thus obtained, a qualitative assessment was done regarding the presence of probable minerals and phases. For the sake of comparison, the X-ray diffractogram of the fly ash (SFA-1andSFA-2) also shown. The X-ray diffraction results of fly ash show the presence of major phases of quartz ('d' values: 3.348, 4.264, 1.820, 2.291, and 2.457), mullite ('d' values: 3.393, 5.385, 2.207, 2.885, and 2.124) and minor phases of hematite ('d' values: 2.543, 2.694) are identified in XRD[11].

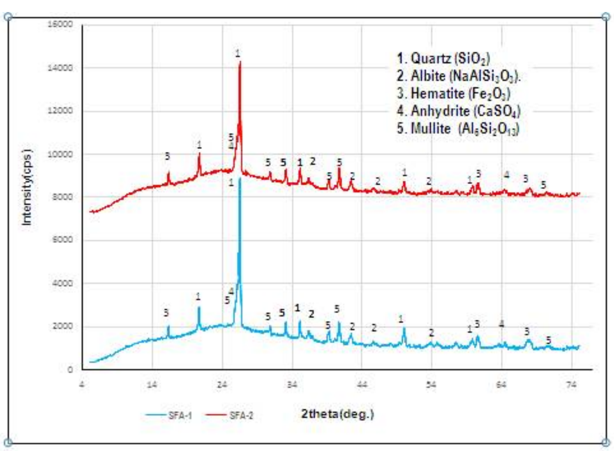

Figure 2: XRD diffractogram obtained for fly ash sample SFA-1and2.

Thermal Characterisation: Thermo gravimetric analysis (TGA) was conducted of oven-dried fly ash samples. The corresponding data obtained from the analysis including onset decomposition temperature, endpoint temperature, and residual weights after decomposition are listed in the Table-2.4 or all experiments, open lid alumina crucibles were used by Mettler-Toledo analyzer (Model TGA/DSC1, STAR[e] System SW 9.20., USA), using N_2 atmosphere (40-50 cm3/min), with the experimental set up consisted of a heating ramp from 25 to 1100°C at 10°C min^{-1}. From the following individual TGA curves and data obtained from them, it can be observed that fly ash powder sample SFA-1, showed single decomposition occurring after 516°C on in general. This decomposition is usually attributed to decomposition of Calcite and other minerals. The fly ash waste sample SFA-2 showed three decompositions, in which the first one may correspond to loss of impurities low molecular weight organic compounds. The first time individual mass gain for each material can be seen on the TGA curve of fly ash powder, each occurring at a different temperature, as shown in Fig.5.6. For the same ash materials, data on thermal analysis were obtained from measurements in N_2 gas atmospheres[1]. As a result, a change of particle properties in conjunction with the oxidation reaction of the ash carbon changed the filtration behavior[2]. The percent mass change that each compound is responsible for is found by measuring a vertical line from the top of the curve to the bottom. H_2O is removed at a temperature around 389°C, $Ca(OH)_2$ decomposes at approximately 467°C and $CaCO_3$ breaks down between 467 and 616°C. CaO, a product of

Ca $(OH)_2$, reacts in a CO_2 atmosphere to form CaCO3 at 616°C. The $CaCO_3$ decomposes into CaO and CO_2. It is important to realize that a significant portion of this Ca $(OH)_2$ was decomposed with weight gain against DTG curve in CaCO3, and it will be also decomposed with weight gain in CaSO4. It is necessary to determine how much $CaCO_3$ was formed from the CaO, and to subtract this from the total $CaCO_3$ present after analysis to find the amount of $CaCO_3$ originally in the ash. This produces CaO and SO_3, as determined by the correct reaction mechanism.

Step 1 (110°C)

$$H_2O\,(l) \longrightarrow H_2O\,(g) \quad (1)$$

Step 2 (389°C)

$$Ca(OH)_2 \longrightarrow CaO + H_2O\,(g) \quad (2)$$

Step 3 (616°C)

$$C + O_2 \longrightarrow CO_2$$

$$CaCO_3 \longrightarrow CaO + CO_2\,(g) \quad (3)$$

$$CaSO_4 \longrightarrow CaO + SO_3 \quad (4)$$

Table 4: Onset and endpoint temperatures obtained for Fly ash samples (SFA-1and2) from TGA curves.

Sample	Onset Temperature (°C)	Endpoint Temperatur e (°C)	Residual Weight after 55°C (%)
SFA-1	34	55	33
	112	151	-
	389	467	-
	616	668	71
SFA-2	516	674	70

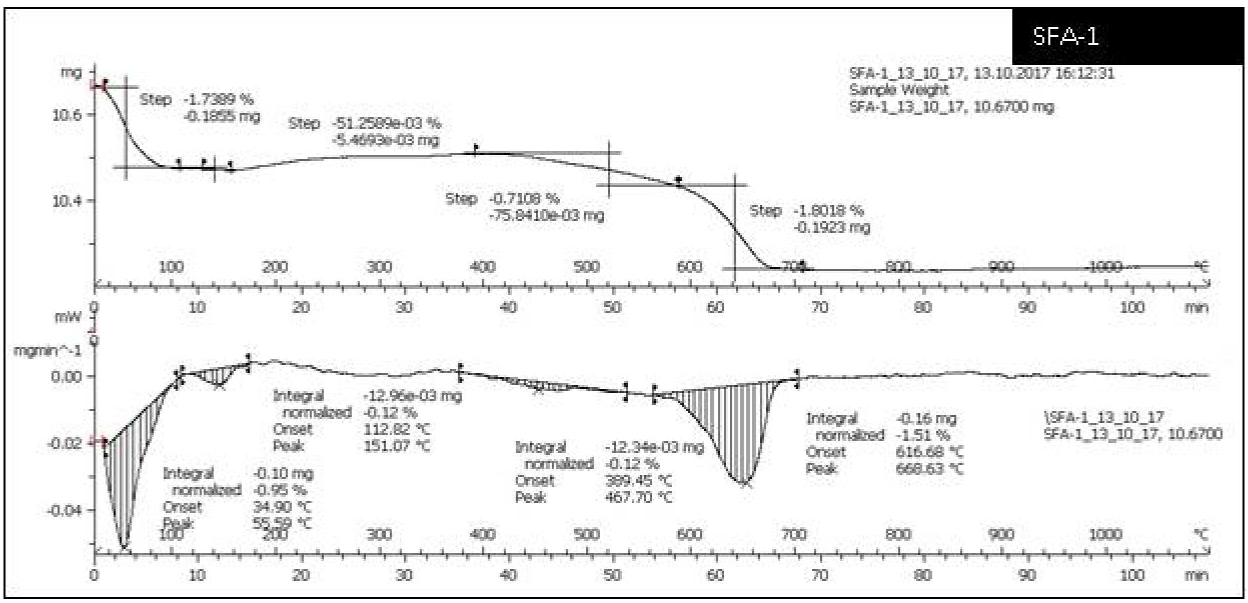

Figure 3: The graph obtained for Fly ash samples (SFA-1 and SFA-2) from TGA curves

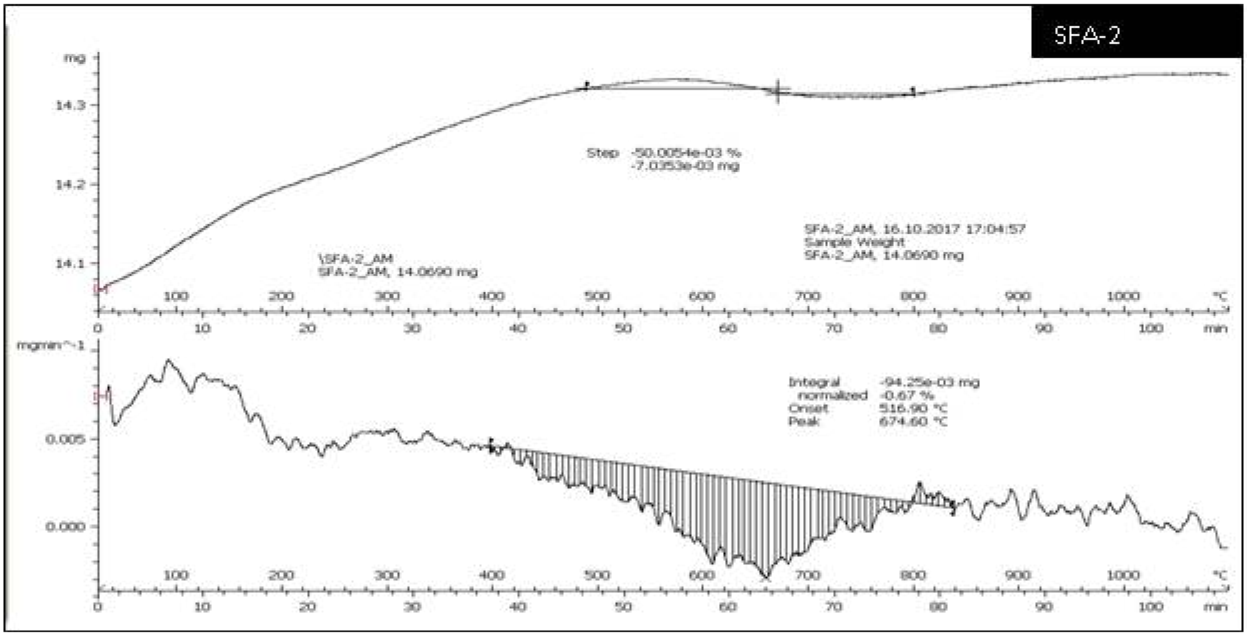

Figure 4: TGA, DSC and DTG overlay curve obtained from the first heating scan of fresh oven dried Fly ash samples

Infra red Spectroscopy: The spectrum of both fly ash (SFA-1and2) reveals that Kaolinite is present as one of the principal mineral matter at 3590, 3450 cm^{-1} band[17]. The aliphatic as well as aromatic carbons are present between 2400-650 cm^{-1}. Aliphatic $-CH_2$ at 2580, 2570cm^{-1}, $-CH_3$ stretching at 1385 cm^{-1}, and aromatic -CH bending present at 820, 650cm^{-1} in the fly ash powder.

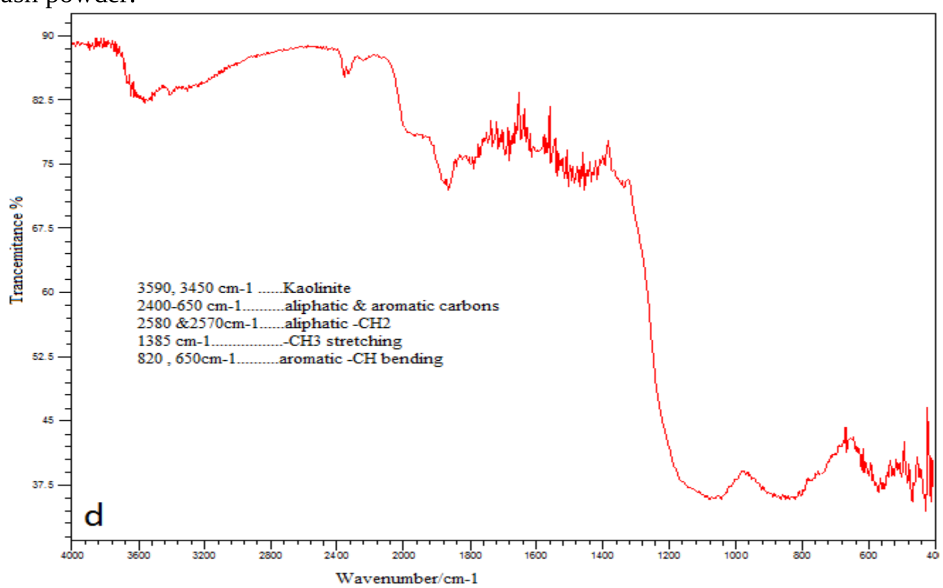

Figure 5: The infra red microscopy (FI-IR) of fly ash (SFA-2).

CONCLUSIONS

Industrial waste poses serious problem for their disposal due to release of toxic elements, which ultimately contaminate the soil, ground water, aquatic life and human health. From the above characteristic of different industrial waste, it is possible to propose their suitability as a row material for application in construction materials like cement, bricks, contrite or polymer composite. This huge quantity of wastes, indeed resource, has to be recycled and used in an effective manner with Life Cycle Assessment Studies. In India, due to the incessant effort of R and D, today is being used 27% of total generation in building materials, road and embankment, land development and agriculture, extraction of metal and cenospheric ash, paints, waste treatment and hazardous waste management. Attempts are being also made to recycle and use huge quantity of Industrial coal combustion residue for reclamation of abundant coalmines for socio techno economic development.. This will open a new avenue for large scale utilization of coal combustion residue followed by providing a multidisciplinary solution to cater the need and safe guard the environment.

REFERENCES

1. N. Chandra, P. Sharma, G. L. Pashkov, E.N. Voskresenskaya, S.S. Amritphale and N. S. Baghel, Coal fly ash utilization: Low temperature sintering of wall tiles, Waste Management 28 (2008) 1993–2002.
2. E.C. Barber, 3M Company, Technical Report (St. Paul, 1999).
3. D.L. Wilcox, M. Berg and D.L. Wilcox, In: Proceedings of Hollow and Solid Spheres and Microspheres (Materials Research Society, Pittsburgh, PA, 1994), p. 3.
4. K.H. Moh and D.L. Wilcox, In: Proceedings of Hollow and Solid Spheres and Microspheres (Materials Research Society, Pittsburgh, PA, 1994), p. 15.
5. P.K. Rohatgi, R. Guo, B.N. Keshevaram, P. Huang,T.J. Srivatsan and J.T. Moore, In: Proceedings of International Symposium on Processing and Fabrication of Advanced Materials IV (ASM International, Cleveland, Ohio, 1995), p. 889.
6. M. Ahmaruzzaman // Prog Energy Combust Sci 36 (2010) 327.
7. R. Sakar, S.K. Das, P. K. Mandal, phase and micro structure evolution during hydrothermal solidification of clay-quartz mixture with marble dust source reactive time, J. Eu. Ceramic Society. 26 (2006) 297-304.
8. S. Wang Environ Sci Technol 42 (2008) 7055.
9. J.-C. Benezet, P. Adamiec and A. Benhassaine Particuology 6 (2008) 85
10. Charles, S., Arunachalam, V.P. 2004, Property analysis and Mathematical modeling of machining properties of aluminium alloy hybrid (Alalloy/SiC/fly ash) composites Produced by liquid metallurgy and powder metallurgy techniques, Indian Journal of Engg. and Material Science, 11, 473-480.
11. H.C. Anilkumar, H.S. Hebbar and K.S. Ravishankar, “mechanical properties of fly ash reinforced aluminium alloy (al6061) composites”, International Journal of Mechanical and Materials Engineering (IJMME), Vol.6 (2011), No.1, 41-45.
12. P. Asokan, M. Saxena, S.R. Asolekar, A process for recycling and utilizing hazardous jarosite released from zinc industries in developing nonhazardous building bricks, Patent Ref. No. 0346NF2005 (2005).
13. A. Anshul, S. S. Amritphale, N. Chandra, N. Ramakrishnan, A. Shrivastava and U. S. P. Verma, Chemically formulated ceramic gamma ray irradiation shielding materials utilising red mud, Advances in Applied Ceramics 108 (2009) 429-437.
14. A. Sarkar, Ruma Rano, G. Udaybhanu, A.K. Basu, A comprehensive characterisation of fly ash from a thermal power plant in Eastern India, Fuel Processing Technology. 87 (2006) 259 – 277.
15. D. Hoff, J. Meyera and G. Kasper, Influence of the residual carbon content of biomass fly ashes on the filtration performance of ceramic surface filters at high temperatures, Powder Technology, 180, (2008), 172-177.
16. E. Wolska, Z. Kristallogr., The effect of cationic and anionic substitution on the α-(Al, Fe) 2O3, lattice parameters. 154 (1981) 69.
17. J. Pascual, F. A. Corpas2, J. López-Beceiro3, M. Benítez-Guerrero1 and R. Artiaga3, Thermal Characterization of a Spanish red mud., Journal of Thermal Analysis and Calorimetry. 96 (2008) 407–412.

Source of Support: None Declared
Conflict of Interest: None Declared