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Utilization of thermal industry waste: From trash to cash

Dipankar Das [*] and Prasanta Kumar Rout

Department of Material Science and Engineering, Tripura University (A Central University), Agartala, Tripura, India.
* Corresponding Author

Abstract: Million tons of coals are being burned every year to meet the electric power requirement in India. Fly ash powder, a by-product recovered from the gases of burning pulverized coal in thermal power plants contains alumina, silica, iron oxide and other heavy metals as well and cause air, soil and water pollution. So, in this present study, attempt have been made to investigate the potential utilization of fly ash collected from north eastern region of India to make some valuable products which will be used in construction industry. Authors have adapted a green technology i.e. geopolymerization technology for making the same. Geopolymerization process is associated with the alkali activation of materials which are rich in amorphous alumino-silicate. In this present investigation, sodium hydroxide is used as an alkaline activator for the dissolution of fly ash powder. The geopolymerization process has been performed using 8 M, 10 M and 12 M sodium hydroxide solution cured under artificial conditions. The mechanical property (compressive strength) was determined by using compression testing machine. Further, the strength data of the geopolymeric samples were co related with the results obtained from various characterization techniques such as scanning electron microscopy (SEM) and Fourier transforms infrared spectroscopy (FTIR).

Keywords: Fly ash, Alkali activation, Geopolymer, Construction industry

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1. Introduction: Polymers are class of materials whose molecules are composed of repeating units called monomers. Polymer can be classified into two types on the basis of backbone of the polymer chain i.e. organic polymer and inorganic polymer. In organic polymer the backbone chain consists of carbon atoms which are covalently bonded with hydrogen or other elements. Inorganic polymers do not contain any carbon atom in the backbone chain; rather contain other element such as Si, Al etc.

In the year 1972, private research laboratory Cordi-Géopolymère in Saint-Quentin discovered an inorganic material called as 'geopolymer' **[1]**. The word 'geopolymer' was first coined by French scientist Joseph Davidovits in 1978 to represent a broad range of materials having networks of inorganic molecules **[2]**. Geopolymers are the inorganic polymers have a chain structures formed on a backbone of aluminium (Al) and silicon (Si) ions. Thereat, geopolymers are sometimes referred to as alkali-activated alumino-silicate binders, soil cement, low-temperature aluminosilicate glass, alkali-activated cement, geocement, alkali-bonded ceramic, inorganic polymer concrete, and hydroceramic. The chemical composition of the natural zeolitic materials is somewhat similar to that of geopolymeric materials, but having an amorphous to semi crystaline in nature unlike zeolite which are mostly crystalline in nature. These inorganic polymeric materials are synthesized in a manner like the thermosetting organic polymers. The polymerization process involves fast chemical reaction under highly alkaline solution on amorphous alumino-silicate precursor materials that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds in amorphous to semi crystalline form with the general empirical formula **[3 - 4]**:

$$Mn\ [-(SiO_2)\ z–AlO_2]\ n.\ wH_2O$$

where: ***M*** is the alkaline element or cation, the symbol (–) indicates the presence of a bond.
n is the degree of polycondensation or polymerization.
z is 1,2,3, or higher, up to 32.

The starting raw materials for making geopolymer are the amorphous alumino-silicate fine powder and alkaline liquids having pH value closed to 13 - 14. Natural minerals like claimed metakaoline or some industrial solid waste such as fly ash can be used as the source materials for geopolymerization process **[5]**. For the production of geopolymer the source materials depends on different factors such as availability, cost, and type of application and specific demand of the user. Furthermore some other admixtures like slag, red mud, mine tailing and plasticizer etc. are used to develop some specific and desirable properties.

The coal combustion residue of thermal power plants i.e. fly ash has been regarded as a problematic solid waste all over the globe. Some of the major issue that are associated with fly ash are vast areas of land is required for disposal and it also contains many trace element such as Cr, Pb, Ni, Ba, Sr, V and Zn etc which are very dangerous to environment. Fly ash being treated as waste, polluting air and water which is a major and serious issue for our society **[6]**. Realizing this issue, in our country various attempts have been made to find out the proper way to utilize such waste solid materials in huge quantities to develop both low and high value added products. Owing to the aluminosilicate nature and amorphous characteristic, there could be possibilities to use this fly ash powder for precursor material for geopolymeric reaction. This present work aims the development of geopolymer samples from different sodium hydroxide (NaOH) concentration by using fly ash from north eastern region of India.

2. Experimental:

The raw material used for this present study was an industrial by product namely fly ash which is the main source of aluminosilicate material. It was collected from National Thermal Power Corporation Limited, Bongaigaon, Assam, India. The alkaline solutions were prepared by dissolving sodium hydroxide (NaOH) pellets (Minimum assay 98.0 %, make: Himedia, India) with required amount of distilled water. The initial solution gets heated because the dissolution process is an exothermic reaction and it becomes unstable **[4].** Thus the solution was prepared at least 24 hour before use and cured at room temperature. The concentration of the alkaline solution is kept at 8 M, 10 M, and 12 M.

Average particle size of fly ash powder was measured using a Malvern Mastersizer particle size analyser, UK. The chemical composition of the powder was measured using X-ray fluorescence (XRF). The morphology of the powders were characterized by scanning electron microscopy (SEM—Jeol JSM-35CF). The powder surface was coated with gold for SEM analysis. Geopolymer are a class of inorganic polymers where the aluminosilicate source material; fly ash will be activated by alkaline solution (NaOH) during mixing process. The mixing was done for 5 minutes to get a homogeneous mixture of geopolymer paste. After completion of mixing process, the geopolymer pastes were casted in a cylindrical plastic mould and top surface of the mould was leveled. The demoulded specimens were artificially cured at oven at 60 ^{o}C for 24 hours.

The compressive strength was measured on a compression testing machine (Model: AIM-314E-DG-1, make: Aimil) using cylindrical specimens. At least six samples were tested and their average compressive strength was reported. The microstructures of geopolymeric specimen were observed using scanning electron microscopy (SEM—Jeol JSM-35CF) where the fracture surfaces was coated with gold. Fourier transformer infrared spectroscopy of fly ash is carried out by BRUKER make ALPHA T model spectrometer. The samples were prepared in the form of KBr pellets for FTIR analysis. Analysis was carried out in the spectral range between 500 and 4000 cm^{-1}. Here in this study FA denotes fly ash; G denotes geopolymer with respective alkali concentration 8M, 10M and 12M.

3. Results and discussion:

The chemical composition of the fly ash powder is shown in Table (1). From the table it can be seen that this fly ash contain lower amount of CaO and higher amount of Al_2O_3 and SiO_2. From this data it was confirmed that these powder is a class-F fly ash powder and can be used as a raw material for Geopolymer **[11].**

Table (1): Chemical composition of fly ash powder

Constituent	Composition (%)
SiO_2	55.6
Al_2O_3	29.80
CaO	1.59
Fe_2O_3	5.91
TiO_2	1.63
MgO	1.08
TiO_2	1.63
K_2O	1.94
Na_2O	0.23
MnO	0.05
SrO	0.04
ZnO	0.03

The particle size distribution plays an important role in reactivity. Figure (1) shows the particle size distribution (PSD) of fly ash powder with particle size. This fly ash is finer in size and all particles are less than 100 µm; 90 volume % particles (d_{90}) are less than 13.62 µm and 50 volume % particles (d_{50}) are less than 2.54 µm.

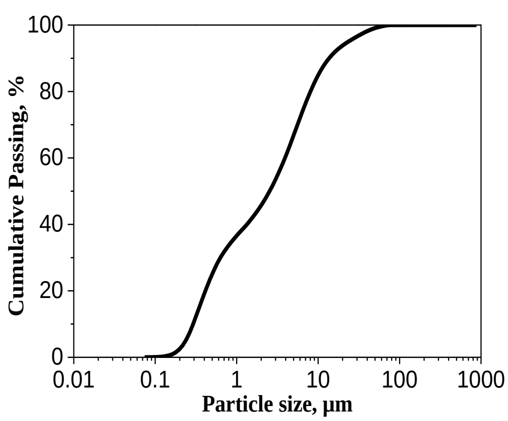

Figure (1): Particle size distribution of raw fly ash powder

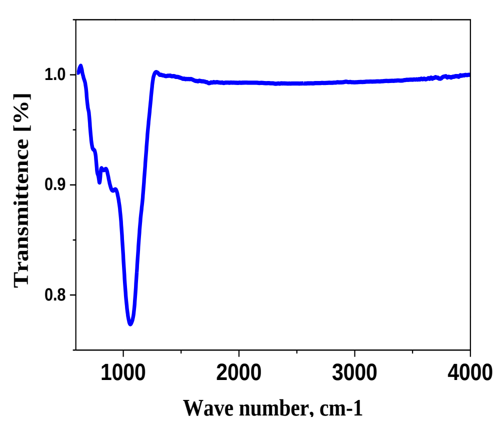

Figure (2): FTIR spectra of raw fly ash powder

Figure (2) shows the FTIR spectra of raw fly ash powder which indicates the molecular vibrations of different bonds at different wave numbers that are present in fly ash powder. The main transmission bands of fly ash powder are at 1065 cm^{-1} and 795.32 cm^{-1}. Here the broad component at 1065 cm^{-1} ascribed to the Si-O-Si or Al-O-Si asymmetric stretching mode [7].

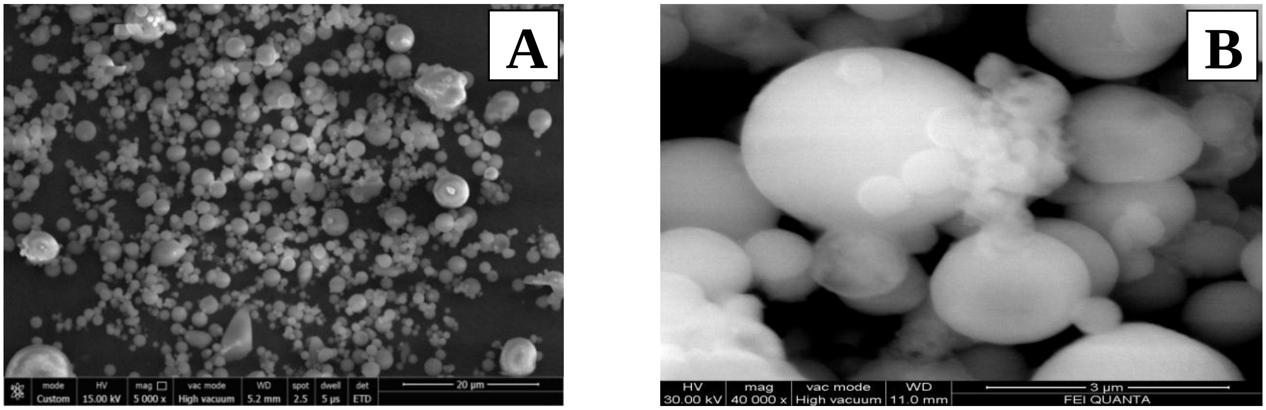

Figure (3): Morphology of raw fly ash powder

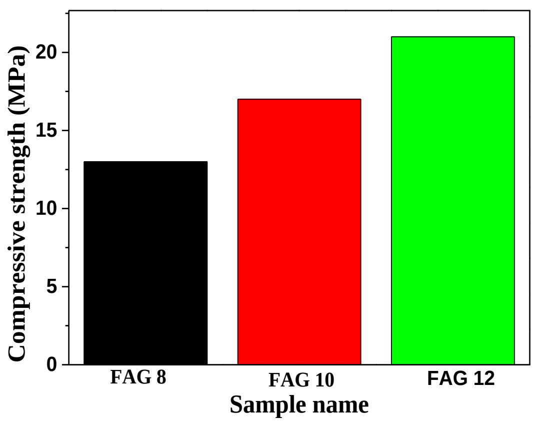

Figure (4): Compressive strength under artificial curing

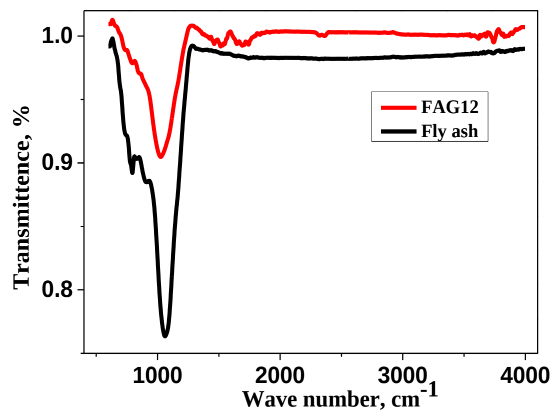

Figure (5): FTIR spectra of FAG12 geopolymer sample

Figure 3 (A-B) shows the morphology of as received raw fly ash powder. Figures 3 (A) shows some angular and irregular shaped particles and figure 3 (B) shows mostly round and spherical shape with smooth texture of different particles sizes. Figure (4) shows the compressive strength of the geopolymeric sample under artificial curing. An increase in sodium hydroxide (NaOH) concentration from 8 M to 12 M increased the compressive strength of the specimen. The maximum strength of the geopolymeric specimen shows at 12 M NaOH concentration under artificial curing which is 21 MPa. Figure (5) shows the FTIR spectra of FAG12 geopolymer sample cured under artificial curing at 60 °C for 24 hours. The main transmission band of as received fly ash powder was at around 1065 cm^{-1} and this band assigned to the Si-O-Si or Al-O-Si asymmetric stretching mode [7]. The reactivity of fly ash powder is strongly depends on intensity of this bond and it was observed that this strong band shifted towards the lower wave number of 1023 cm^{-1} in the geopolymeric specimen [8]. This shows that during the geopolymerization reaction new microstructure developed by the dissolution of the fly ash amorphous phase in the strong alkaline solution and resulting in the formation of new product [6, 9].

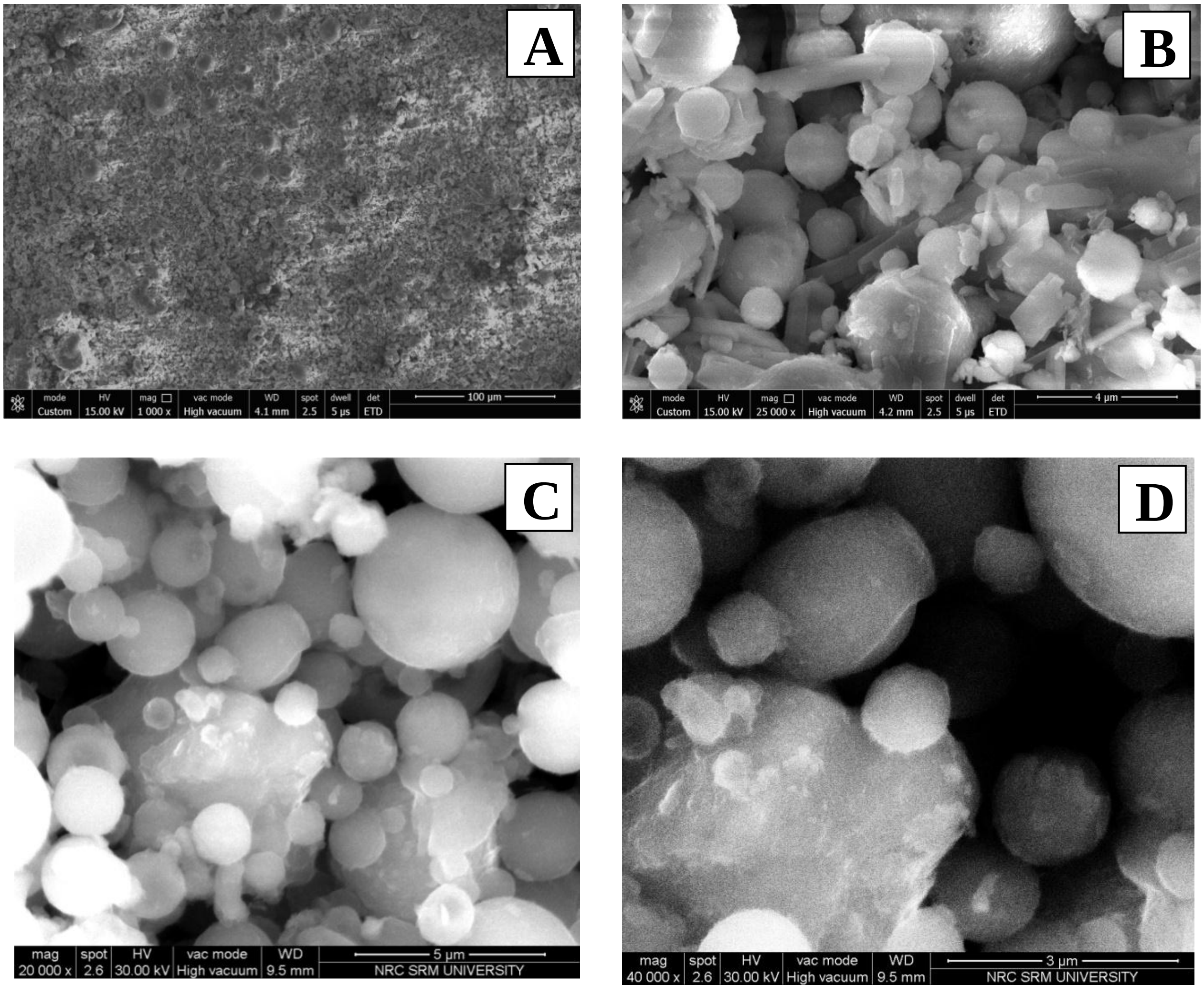

Figure (6): SEM micrographs of FAG12 geopolymer sample cured at 60 ^{O}C

Figure 6 (A-D) illustrates the microstructure of hardened FAG12 geopolymeric specimen at different magnification synthesized at 60 ^{o}C for 24 hour. Figure 6 (A) shows the morphology of geopolymer gel under lower magnification and figure 6 (B) shows that the geopolymeric specimen is formed with many needle or stripe-shaped particles and this needle shaped particles are formed due to the enormous alkali solution encompassed the fly ash particles in the geopolymer paste **[9]**. This needle shaped or stripe-shaped particles indicate that with the help of extended curing this geopolymeric specimen may have the capability to increase the compressive strength **[10]**. Figure 6 (C-D) shows the gel like substances where some particles are partially and some are fully reacted.

Conclusions: The chemical composition of fly ash powder showed that it is a class F type fly ash and can be useful for making geopolymer product. The compressive strength of the geopolymer is also dependent on NaOH concentration and the 12 M sodium hydroxide concentration shows 21 MPa strength. On the basis this preliminary experiment and results it can be interpreted that there is a scope for making geopolymer by using fly ash from north eastern region, India.

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