Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 2, Number 1; January-March, 2015, pp. 56-59

http://www.krishisanskriti.org/jbaer.html

CCRs and Their Potential Use in Mine Stowing–An Overview

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Abstract—*More than 65000 acres of land in India has been occupied by the coal combustion residues (CCRs) produced from the thermal power plants. The storage of this huge quantity of unused CCRs leads to ecological and environmental imbalance. CCRs find wide range of applications in day to day life. The use of CCRs for mine backfilling has been considered as an opportunity for their bulk utilization. This paper deals with the physico-chemical properties of CCRs and their application in mine stowing. This paper also discusses on the need for future research on the environmental impacts of backfilling with CCRs for their expanded use in mine backfilling and mine site rehabilitation. It is envisaged that this paper will encourage the producers of CCRs, scientists, technocrats, entrepreneurs, consumers and decision makers to jointly put an effort for evolving a suitable paradigm for effective management of Coal Combustion Residues.*

Keywords: *CCR; fly ash; physico-chemical properties; mining; stowing; backfilling.*

1. INTRODUCTION

The large amount of coal combustion residues (CCRs) produced from thermal power plants has become a major environmental concern universally. Environmental pollution caused by the coal based thermal power plants all over the world is cited to be one of the major sources of pollution affecting the general aesthetics of environment in terms of land use, health hazards and polluting air, soil and water in particular. Coal is the primary source of energy. Since there is a wide consensus on the requirements of energy worldwide for meeting the increasing energy demand, the coal combustion will continue to increase in near future as well. The distribution of coal consumption worldwide in 2012 shown in Figure 1 depicts that India stands third in terms of coal combustion globally after China and USA. With increasing coal combustion for power generation, the global generation of CCRs is expected to reach 2000 MT per annum by the year 2020. However, there is a huge imbalance between the generation and utilization of these CCRs. During 1993, the utilization of CCRs in India was only 2.3% out of the total annual generation of 35 MT. One of the main reasons for this poor utilization level of CCRs is the lack of awareness among the users on the beneficial aspect of CCRs. Now in India, quality CCRs from modern Thermal Power Stations confirming to IS 3812 are available and various proven research work through demonstration trials on their use has substantially increased. As a results, presently fly ash has been used up to 45% of the total generation in India in various applications such as building materials, construction of road and embankment, land development and agriculture, extraction of metal and cenospheric ash, paints and waste treatment.

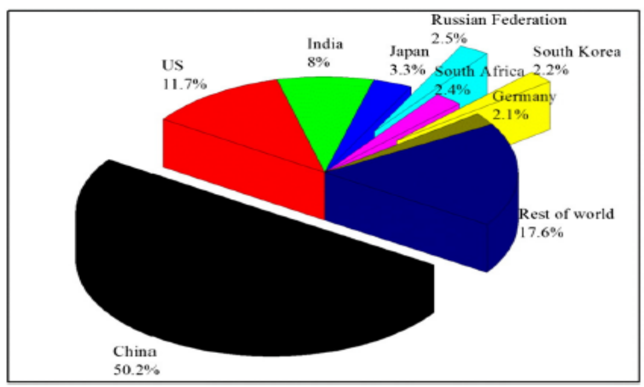

Fig. 1: Distribution of coal consumption worldwide in 2012 (Yao et al., 2015)

CCR is the world's largest mineral resource available and it's processing, handling ultimate utilisation and safe management are the major concern for the environmental sound management and sustainable development. These days mining industry is facing an acute shortage of river sand due to its increasing application in civil engineering. As a result, a large number of underground coal mines are left unstowed after excavation of coal leading to surface subsidence. There is a need for an alternative stowing material which is available in sufficient quantity and at minimal cost. At the same time, coal combustion residues occupying a substantial area of land in the form of ash ponds and causing environmental pollutions has the potential to be used in stowing or backfilling of the underground mines. Since CCRs are generated from the thermal power stations, which are situated nearby to the coal mines, will cut short the cost of stowing as compared to other stowing materials such as river sand. It is envisaged that the potential use of CCRs in stowing or backfilling will solve the land crisis for its storage and minimize the host of environmental hazards.

2. WHAT IS CCR?

Coal combustion residues or CCRs is a collective term referring to the residues produced during the combustion of coal in thermal power plants. It includes fly ash, bottom ash, boiler slag, and fluidised bed combustion ash and other solid fine particles. But, the CCRs is a universal by-product being effectively used universally as a resource/raw materials in polymer matrix composites, metal matrix composites, cement–concrete and ceramic composites for many applications. Many industries like construction, ceramics, mining, agricultural industry etc. are the major industrial partners universally using fly ash. The utilization of CCRs in different purposes has been shown in Figure 2. There is a growing demand for CCRs universally and most of the countries depend mainly on coal combustion process to fulfil their electricity requirement. Therefore, CCRs experts, universally, are to be involved in policy decision before implementation of any such regulation for the benefits of each and every citizen of the World.

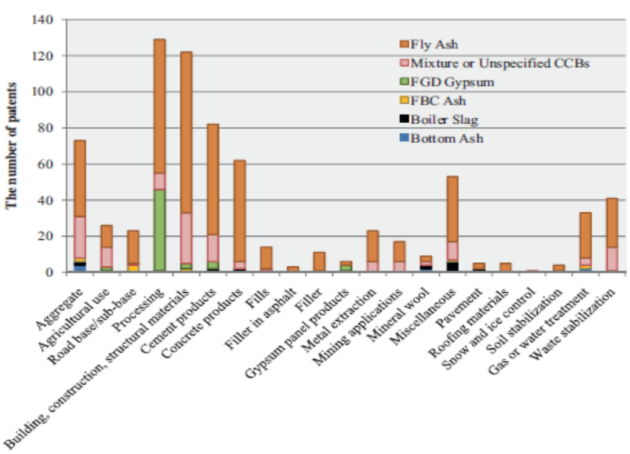

Fig. 2: Utilization of CCRs

3. PHYSICO-CHEMICAL PROPERTIES OF CCRS

3.1 Physical properties

Fly ash is a non combustible particulate matter removed from coal fired boilers. It is generally amorphous and contains good amounts of ferro-aluminosilicates. The CCR particles are generally grey in colour; however, some of the pond ashes are blackish grey. But when fly ash is mixed with bottom ash, overall unburnt carbon content of the CCRs varies between 3-5%. Some of the physical characteristics of CCRs in India have been portrayed in Table 1.

Table 1: Physical properties of Indian CCRs (Ashokan et al., 2005)

Parameters	Range
Bulk density (kg/m^3)	960-1500
Water holding capacity (%)	35-55
Porosity (%)	30-35
Colour	Greyish
Silt (%)	10-35
Clay (%)	0.5-15
Sand (%)	60-80
pH	3.5-12.5
Electrical conductivity (dS/m)	0.075-1.0
Surface area (m^2)	0.1038-2.4076

3.2 Chemical constituents

The major constituents of CCRs are silica, alumina and iron oxides (Mishra and Das, 2010). One of the major concerns with disposal of CCRs is the leaching of heavy metals to surface and underground water sources, which may contaminate the ground water nearby the ash disposal area. Most of the heavy metals/trace elements in Indian CCRs found in lower concentration than that in other countries, which is one of the advantages for its utilisation in agriculture and in embankment. Various elements present in Indian Coal Combustion Residue have been depicted in Table 2. Apart from these, CCRs also contain trace amounts of few radioactive elements.

Table 2: Elemental composition of Indian CCRs (Ashokan et al., 2005)

Parameters	Range
Silicon (Si)	27.413-29.554%
Sulphur (S)	0.07-0.70%
Sodium (Na)	0.04-0.055%
Aluminium (Al)	15.167-20.45%
Iron (Fe)	4.447-6.662%
Calcium (Ca)	0.40-0.77%
Manganese (Mn)	0.002-0.85%
Magnesium (Mg)	0.02-0.9%
Phosphorous (P)	0.06-0.3%
Potassium (K)	0.14-1.8%
Arsenic (As)	5-70 ppm
Boron (B)	100-1000 ppm
Barium (Ba)	26-1670 ppm
Chromium (Cr)	10-350 ppm
Cadmium (Cd)	1-25 ppm
Copper (Cu)	40-100 ppm
Cobalt (Co)	7-129 ppm
Lead (Pb)	10-140 ppm
Nickel (Ni)	30-265 ppm
Mercury (Hg)	0-0.005 ppm

Apart from these elements, certain oxides form the basic constitution of fly ash. The principle constituents of fly ash are silica, alumina, ferrous oxides and calcium oxide with varying amounts of carbon as measured by a Loss on Ignition (LOI) test (Mishra and Das, 2010). The composition of various oxides present in fly ash derived from different varieties of coal has been listed in Table 3. Generally, the metal oxides in fly ash are found in an increasing order as SiO_2 > Al_2O_3 > Fe_2O_3 > CaO > MgO > K_2O > Na_2O > TiO_2, but it may vary according to the nature of coal and combustion conditions.

Table 3: Various metal oxides present in fly ash derived from different varieties of coal (Simmons et al., 2003)

Component (wt%)	Bituminous	Sub-bituminous	Lignite
SiO_2	20-60	40-60	14-45
Fe_2O_3	10-40	4-10	4-15
Al_2O_3	5-35	0-30	10-25
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
SO_3	0-4	0-2	0-10

4. UTILISATION OF CCRS

There is a dire need to utilise this resource to its full potential. The residues produced during the combustion of hard coal in power stations create a disposal and thus an environmental problem but if somehow they can be brought to use it can prove a great asset to nature. So far we do lack the appropriate technology to convert this so called "waste" into a useful resource. Other than the harmful effects, CCRs have huge upside potential and they are being used in ceramic industries, cement making and soil amelioration etc. The total utilization of CCRs in India is said to reach 45%, in US it is slightly ahead with 60% and China leads the pact with utilization level of 75%. Table 4 portrays all the major areas of utilization of CCRs with advantages and disadvantages. The general utilization of CCRs in mine site has been pictorially shown in Figure 3.

Table 4: Principle applications of CCRs (Yao et al., 2015)

Applications	Advantages	Disadvantages
Construction industry	1. Replacement of cement with fly ash reduces the water demand along with production costs but it does enhance workability of concrete. 2. One of the best value-added uses and a large amount of ash is being consumed.	1. The ash producing agents are influenced by seasonal factors and their operations peak at different times. 2. Compressive strength of concrete is affected at early ages, especially under cold conditions.
Catalysis	1. Used as a catalyst in various chemical reactions because of being cost effective and environment friendly. 2. Makes use of relatively very small quantity of ash but it is among the best value added uses.	1. Do not find intensive applications in industries. 2. Releases certain heavy metals such as Hg which can cause pollution.
Environmental protection	1. Finds gaseous and aqueous applications as it is a low cost potential adsorbent. 2. It is also used as a sorbent for the flue gas desulphurization process.	1. Adsorbing capacities vary with the properties of different ashes. 2. Fly ash adsorbents have a limited adsorption capacity.
Soil quality maintenance	1. Increases the availability of plant nutrients except organic C and N; reduce the dissolved P content in porous soil. 2. Can be used as a substituent for lime and dolomite because of cost effectiveness and non polluting, although do not replace chemical fertilizers or organic manures.	1. Higher rates of ash when applied have potential phytotoxic effects. 2. Lead to an increase in soil salinity for higher concentration of total dissolved solids, total hardness, cations and anions in fly ash leachates.

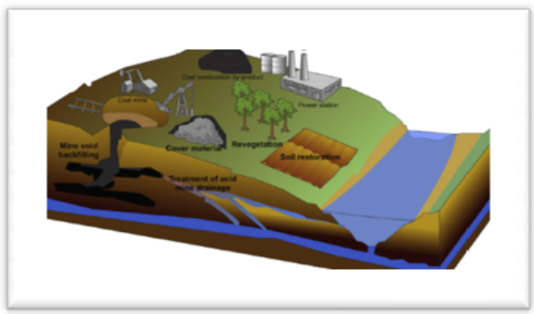

Fig. 3: Use of CCRs in mine sites (Park et al., 2013)

5. APPLICATION OF CCR IN MINE STOWING

River sand is considered as a very good stowing material. However, due to its increasing use in construction works these days, there is a scarcity of sand and as a result; many coalfields are facing the problems in stowing. The use of CCRs for mine stowing has been considered as an opportunity for the bulk utilization of CCRs. Backfilling of underground mine voids with these materials presents the potential to reduce acid mine drainage, limit the risk of land subsidence and minimise and control the likelihood of mine fires. Various properties of CCRs are comparable to rock salt, potash or mill tailings which are currently utilized in mine stowing.

The presence of SiO_2 in abundance in CCRs increases the strength and the presence of CaO enhances the cementing properties of the stowed mass. Since the CCRs contain a very negligible amount of unburned carbon, there is no risk of spontaneous heating if utilized as a stowing material in underground coal mines. Ash fill shows better post-failure properties in case of bord and pillar mining. In a model test carried by Galvin and Wagner (1984), it was observed that by allowing ash fill to settle out properly, the strength of the coal pillars increased by a considerable margin in comparison to other stowing materials. The test confirmed that after 200 days of ash settling in the voids, strength of model coal pillars with height : width ratio of 1 was increased by 50% and those with height : width ration of 2 increased by 40%. At 400 days of curing/settling, these values further consolidated by approximately 10% each to 60% and 50% respectively. Further, fly ash when mixed with lime gets cementing property, which acts as a cheap and environment friendly stowing agent.

When CCRs are used for mine backfilling; the ash, the mine water or groundwater and the rock strata of the mine site interact together, and collectively impact the environment. Therefore, the test includes not only to monitor element mobility when the CCRs are exposed to water, but also interaction of the products of CCRs and mine water with the associated rock strata. The number and location of monitoring wells, the frequency and duration of sampling, and water quality parameters for analysis should be considered before backfilling in order to monitor potential contamination of the environment. Monitoring should be continued until the site is regarded as stable and without risk of degradation of ground or surface water by CCRs.

The broader objective of mine backfilling with CCRs is not only the prevention of surface subsidence, but also the bulk disposal of CCRs. There is a lack of monitoring on after effect of utilization of CCRs in mine backfilling and other mine-related uses, a feature that can be related partly to the lack of regulations or guidelines on the use. Therefore, future research on environmental impacts of backfilling with CCRs needs to focus on the leaching of elements from CCRs and their impact on the ground water before disposal in mine sites.

6. CONCLUSION

Coal combustion residues are one of the most abundant high-volume "waste" materials available. Coal combustion residues have great potential to be used for mined land rehabilitation because of their abundance and physicochemical properties to ameliorate the acidity of Acid Mine Drainage and to improve soil condition. Furthermore, stowing the mine voids using CCRs can be considered as utilisation as well as bulk disposal. Attempts are also being made to recycle and use huge quantity of CCRs for reclamation of abundant coal mines for socio-techno economic development. Long term perspectives of CCR management is deemed imperative and now it is necessary for the CCRs generators, scientists, technocrats, entrepreneurs, consumers as well as decision makers to jointly put an effort for evolving a suitable paradigm for effective management of Coal Combustion Residues. However, it is necessary to establish regulations for the expanded use of CCRs for mine backfilling and the broader realm of mine site rehabilitation.

7. ACKNOWLEDGEMENT

The authors are deeply grateful to Dr. D.P. Mishra for his kind inspiration and help which served a great deal in making this paper.

REFERENCES

[1] Skarzynska, K.M., 1995. Reuse of coal mining wastes in civil engineering. Waste Management, Vol. 15, No. 2, pp. 83-126.

[2] Demir, Ilham., Hughes, R.E., DeMaris, P.J., 2001. Formation and use of CCR. Fuel 80 (2001) 1659-1673.

[3] Yao, T., Ji, X.S., Sarker, P.K., Tang J.H., 2015. A comprehensive review on the application of coal fly ash. Earth-Science Reviews, 141: 105-121.

[4] Blissett, K.S., Rowson, N.A., 2012. A review of the multicomponent utilization of coal fly ash. Fuel, 97: 1-23.

[5] Park, J.H., Edraki M., Mulligan, D., Jang, H.S., 2013. The application of coal combustion by-products in mine site rehabilitation. Journal of Cleaner Production 84 (2014) 761-772.

[6] Mishra, D.P., Das, S.K. 2010. A study of physico-chemical and mineralogical properties of Talcher coal fly ash for stowing in underground coal mines. Material Characterization, 61: 1252-1259.

[7] Mishra, D.P., Das, S.K., 2013. Application of polymeric flocculants for enhancing settling of pond ash particles and water drainage from hydraulically stowed pond ash. International Journal of Mining Science and Technology 23 (2013) 21-26.

[8] Zienkiewicz, P.F., Simmons, J.S., 2003. Evaluating the environmental risk of backfilling mines with coal ash. 2003 SME Annual Meeting, Feb. 24-26, Cincinnati, Ohio.

[9] Coal Combustion Residual beneficial use evaluation in February 2014.

[10] Ashokan, P., Saxena, M., Asolekar, S.R., 2010. Recycling hazardous jarosite waste using Coal Combustion Residue. Materials Characterization 61 (2010) 1342-1355.

[11] Park, J.Y., 2014. The evolution of waste into a resource examining innovation in technologies reusing coal combustion by products using patent data. Research Policy 43 (2014) 1816-1826.

[12] Ashokan, P., Saxena, M., Asolekar, S.R., 2004. Coal combustion residues- environmental implications and recycling potentials. Resources, Conservation and Recycling 43 (2003) 239-262.

[13] Sinha, A.N., Sehgal, V.K., 1996. Geotechnical rationale and scope for fly ash and side bolts as alternatives to sand in pillar reduction and stabilization. Mineralogy-Petrology Symposium (1989) 117-121.