Overview of coal fired power generation

The burning of coal for the production of electricity supplies around 40% of the UK electricity as shown in Figure 1. Coal fired generation is very seasonal because it is mainly used to provide the extra power needed at peak times and in the colder months.

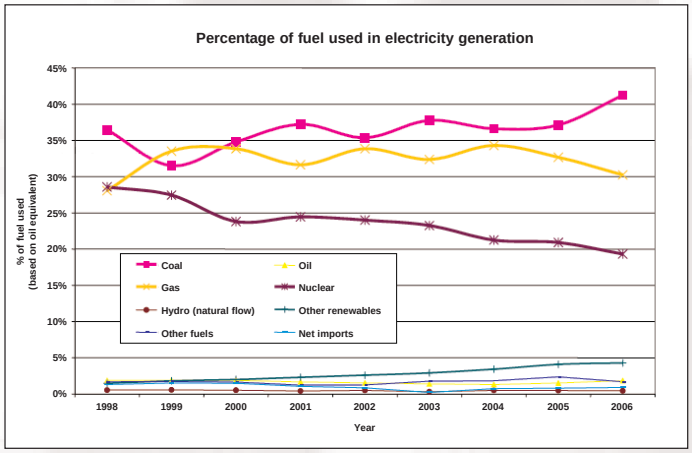

Figure 1 - Fuel sources for electricity generation

With the well publicised issues of security of electricity supply relating to natural gas, the gradual decline of the existing nuclear power stations, the issues and timescales involved with building new nuclear power stations and slow development of renewable forms of electricity generation and their dependence on the forces of nature, it would appear pulverised coal fired power generation will be necessary for some years to come. Even in future years the development of clean coal power stations with carbon capture will still lead to the production of ash. As there are estimated to be in excess of 200 years of coal in reserves around the world, such an energy resource cannot simply be ignored.

Ash is an inevitable result of burning coal. It results from soil and minerals laid down with the coal many millennia ago. In a pulverised coal fired power station there are two types of ash produced, Pulverised Fuel Ash (PFA), also known as fly ash in many countries, and Furnace Bottom Ash (FBA).

Environmental Issues

PFA and FBA are chemically identical materials though they are extracted from differing points within the burning cycle. FBA falls to the bottom of the furnace and PFA is carried through with the furnace gases, having to be extracted using electrostatic precipitators. Further details of the operation of a power station can be found on our web site[1] and general information brochure.

The properties of PFA and FBA are well understood and a generic environmental risk assessment is available on the UKQAA web site which details the element composition and leaching properties of PFA, and therefore FBA. When these materials are used within the recommendations of the UKQAA they pose no significant risks to the environment.

Typical Applications

Power station ash has a range of differing applications as shown in Figure 2. FBA is predominantly used within the block making industry as a lightweight aggregate for making lightweight concrete blocks - see Technical Datasheet 7.0. PFA has a far wider range of applications as an aggregate that include;

- Fill material - for embankments - see Technical Datasheet 2
- Grouting - for filling of voids in the ground - see Technical Datasheet 3
- Concrete - used as a filler aggregate - see Technical Datasheet 1
- Road Construction - As a binder and aggregate on road sub-bases - see Technical Datasheets 6.x series

Both PFA and FBA are used as alternatives to both natural and manufactured aggregates. Producing natural aggregate has a range of environmental impacts, depending on the extraction, crushing, screening, etc operations involved. An estimate for the factory gate environmental cost of producing 1 tonne of natural aggregate is ~21kg of CO_2, though this must be considered a conservative value.

In addition PFA can be used as a cementitious material, partially replacing Portland cement in concrete, mortar and grouts. As the environmental impacts associated with the manufacture of Portland cement emit ~960kg/tonne[2] of CO_2, considerable benefits by the substitution of some of the cement, both in the cement works and at the concrete, mortar or grout production plant can be achieved.

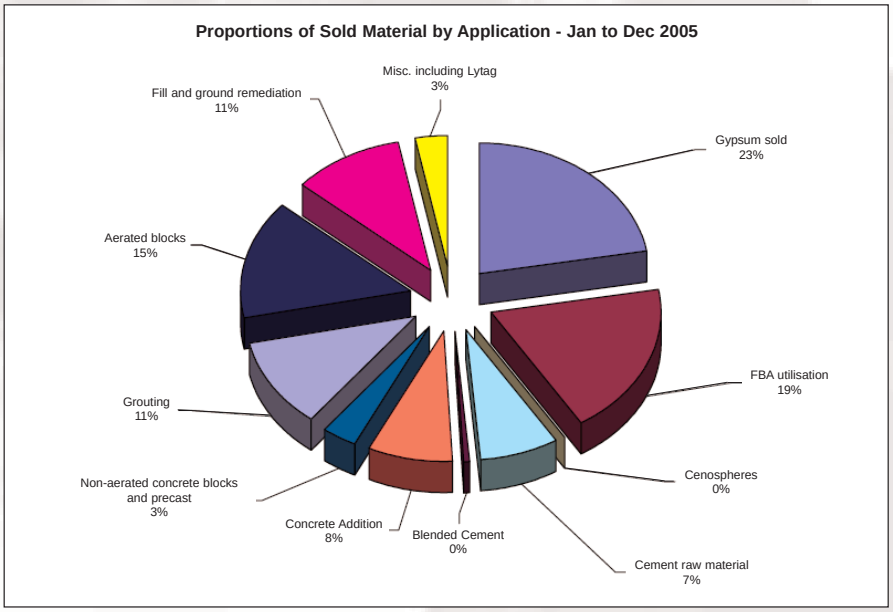

Figure 2 - Coal fired power product utilisation

FBA

All the UK coal fired power stations have what's known as 'wet bottom' furnaces, where the ash is flushed from the bottom of the furnace using water. This means the FBA is effectively washed in copious quantities of water making it suitable for use as an aggregate. Just over 1,000,000 tonnes of FBA is produced annually and virtually all the UK production of FBA for many years has been used in the manufacture of lightweight concrete blocks. Due to its method of production most leachable materials are removed and as a result there are no known risks to the environment or to the user from FBA.

Figure 3 - FBA being flushed in settlement pits

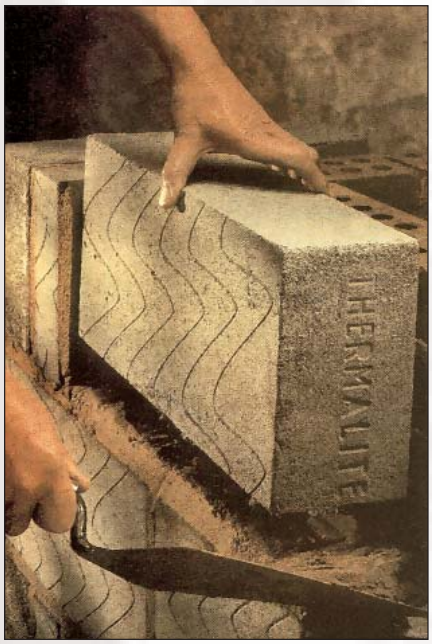

Figure 4 - Blocks made with 85% ash

Because there are only a limited number of alternatives to FBA consisting of manufactured aggregates or natural pumice, the direct assessment of the reduction in environmental impacts are somewhat difficult.

- On a weight for weight basis and in comparison with natural aggregates the overall CO_2 savings of using FBA are in excess of 210,000 tonnes per annum.
- FBA is not simply replaced with commonly available naturally occurring aggregates, because FBA is a lightweight material of density between 800 and 1100 kg/m^3. Compensating for the density differences would suggest CO_2 emissions savings of ~300,000 tonnes p.a.

- One natural aggregate with similar properties is pumice which is imported. Pumice is not found within the UK and is sourced in Italy and similar volcanic regions. This importation adds to the environmental impacts associated with the transport issues and virgin aggregate depletion. Chemically pumice is very similar to FBA, as they both originate from heating of natural minerals to very high temperatures either in the volcano or within the power station. The overall CO_2 emissions for its production are unknown, being easy to quarry but requiring transportation over significant distances.
- Alternatively there are manufactured alternatives such as sintered PFA aggregate[3] (Lytag) and expanded clay aggregates. At the time of writing this sintered PFA aggregates are not being produced within the UK though they are being imported from sources within the EU. Expanded clay aggregates are being used by some block manufacturers, but again these require both virgin clay and heat for their production.

In reality the estimated savings from the use of FBA of 300,000 tonnes of CO_2 emissions are highly conservative.

PFA

PFA represents the largest proportion of the ash produced from a power station, with about six times the amount of FBA being produced. This is a fine powder (like talcum), grey to dark grey in colour. It is used in a wide variety of applications as described in our Technical Datasheets. However, for a variety of reasons not all PFA is used, with about half of the annual production being landfilled.

The environmental benefits of using fly ash are in some senses easy to assess. Invariably fly ash is substituted for either virgin aggregate or Portland cement in all applications. As ~ 2,400,000 tonnes of PFA are used, predominately as filler aggregate, we can easily calculate a reduced environmental impact of about 56,500 tonnes of CO_2 per annum. However, it can be difficult to fully evaluate whether the PFA is replacing cement or virgin aggregate. Clearly significant benefits are being achieved both as a cementitious material and as an aggregate in some applications, for example in PFA grouting.

The following example of PFA grouts shows that the considerable technical advantages of PFA can result in further savings of overall CO_2 emissions;

PFA grouts are more sustainable because;

1. Fly ash grouts need less cement for a given strength than natural aggregate. This is because fly ash reduces the water content of the grout and is pozzolanic.
2. Fly ash has a lower particle density (~2.3kg/m^3) than natural aggregate (~2.6kg/m^3), so about 13% less material by weight is required.
3. Fly ash slows the setting time of the grout, which is beneficial to much grouting work.
4. Fly ash grouts do not bleed significantly and can be pumped long distances. This makes them very efficient at filling of the void completely with minimal disruption.

Using PFA in grouts has been shown by one contract to reduce vehicle movements by 40% and material cost by ~50% when compared to a Portland cement grout made with virgin sand. By assuming PFA is filler aggregate only based on current usage, CO_2 savings of ~12,000 tonne p.a. are being realised. However, by adjusting for the technical benefits of reduced Portland cement content, the lower density and reduced haulage, these savings increase to ~40,000 tonnes p.a.

Benefits are also apparent using PFA as a fill material. This is a direct replacement for virgin aggregates and has the benefit of being a considerably lower density than natural aggregates and readily available in very large quantities increasingly supplied by train.

Aerated concrete block manufacturers use PFA as both aggregate and binder, with an aerated block containing ~80% ash. As the virgin alternative to PFA is ground sand, the CO_2 reductions by using PFA equate to at least ~17,000 tonnes p.a.

Portland cement (CEM I), by the nature of its chemistry and manufacture, has a relatively high CO_2 emission of ~960 kg/tonne. When PFA (fly ash) is used in concrete environmental savings can equate to ~20% and 30% reduction in overall CO_2 for 30% and 50% ash contents respectively for mixes designed with equal 28 day strength.

About 400,000 tonnes of fly ash are used in concrete production p.a. this equates to ~250,000 tonnes of CO_2 prevented from reaching the atmosphere p.a. In addition, the cement industry is adding fly ash to cement as a kiln feed material, as a Minor Additional Constituent (MAC) and in the production of blended fly ash cements. This further reduces the overall CO_2 emissions in producing concrete, mortars, grouts, etc.

Overall

It is difficult to estimate the overall benefits of using coal fired power station products in reducing emissions accurately, but a reduction of at least 600,000 tonnes of CO_2 per annum has been calculated. As only about half of the PFA produced is currently utilised, this figure could be doubled in principle.

Sustainability Issues

In most applications fly ash replaces virgin aggregate or Portland cement, both of which have an environmental impact in their production and of the depletion of virgin resources. Fly ash is readily available as it has been produced since the 1950's, with most of it being landfilled. However, much of this fly ash is no longer accessible due to station closures and the sites being subsequently redeveloped. On the remaining coal fired power stations it is estimated there is some 55,000,000 tonnes of fly ash readily available and a further 60,000,000 tonnes that may be accessible if required. As power generation based on coal is likely to continue for many years, the resulting fresh ash production plus the existing stockpiles form a readily available mineral resource for future generations.

Much of this stockpile material would need some processing, such as extraction, screening, drying and possibly beneficiation, grinding or classification for some applications, e.g. for use in concrete. Such technologies already exist and, unlike some other secondary materials, importation is not an issue as fly ash availability outstrips demand. At the current rate of utilisation existing stockpile material alone could last for at least 30 years.

It must be remembered that in addition to the environmental benefits and unlike many other recycled/by-products, using PFA has many technical advantages, for example in concrete by reducing the risk of ASR, chloride ingress, etc - see Technical Datasheet 1. In practical terms fly ash concrete gains strength with time and can be far more durable than implied from the 28 day strength, thus extending the life of the structure. By making longer lasting structures the environmental impact of building is diluted. Many structures are now designed with 100 year life in mind, in which fly ash can play a major part in achieving this longevity.

To take advantage of the benefits of fly ash concrete to ensure longevity requires considerable thought on the part of the designer, who must allow for flexibility of use and ease of maintenance. However, the Romans have proven longevity is possible with fly ash concrete structures such as the Pantheon. Built between 118 and 128 AD, the dome is a volcanic fly ash concrete structure that has stood the test of time. PFA structures can do the same and reduce the overall environmental impacts substantially in comparison with traditional construction.

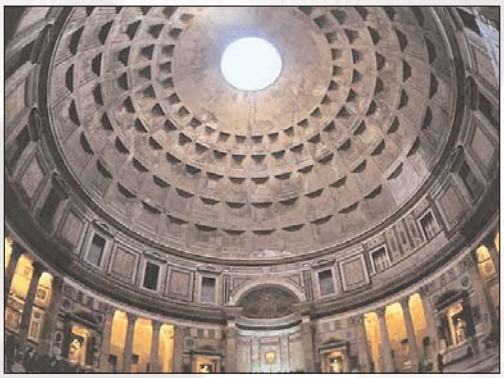

Figure 5 - The Pantheon

Conclusions

Using coal fired power station ash products is generally always beneficial to the environment in some way as they replace either Portland cement and/or virgin aggregates. As approximately 50% of the PFA produced is currently landfilled, the existing stockpiles represent a considerable mineral resource for future generations.

The UKQAA aims to develop more applications for the products and expand existing markets to achieve an aim of 100% utilisation to the benefit of the environment and enhancing sustainability.

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[1] www.ukqaa.org.uk

[2] Assumes no minor additional constituents used or reduced CO_2 emissions from secondary fuels

[3] See UKQAA Technical Datasheet 4

In general usage the term ‘fly ash’ is used for pulverized coal ash but it can also cover ash from burning other materials. Such ‘fly ash’ may have significantly differing properties and may not offer the same advantages as ash from burning pulverized coal. UKQAA datasheets only refer to PFA / fly ash produced from the burning of predominantly coal in power stations.