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The Environmental Impacts of Using Fly Ash – the UK Producers' Perspective

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ABSTRACT

Fly ash, or Pulverised Fuel Ash (PFA) as it is known in the UK, has been used for over 50 years for a wide range of applications. With the recent upsurge of interest in the impact of industry on the environment, some have questioned using PFA as a construction material. This paper reviews existing knowledge and presents some recent findings of research on the environmental impact of PFA.

The chemistry of PFA reflects the mineral origins of the coals when formed millions of years ago. The combustion process concentrates these minerals. However, most elements are held in the glassy particles that are formed in the furnace. While the trace element composition may indicate potential for environmental effects, the available leachable elements are minimal. With proper design, unbound PFA can be used as a fill material posing only negligible risk, even to sensitive aquifers.

Recently, an examination of leachates adjacent to large PFA embankments of varying ages has been carried out by Nottingham University. This project has shown no significant contaminants associated with the PFA. It also reviewed the release of radon gas from PFA and reported there are no significant radiation risks. A generic environmental risk assessment, bringing together data from these reports, UK power stations, various environmental sources, research papers, etc also concludes there are no significant environmental risks associated with the proper use of PFA as a fill material. This looked at trace elements, poly-aromatic hydrocarbons, dioxins, phenols, etc.

This paper concludes that PFA is an environmentally harmless material that can be safely used in bound and unbound applications.

USAGE OF PULVERISED FUEL ASH (PFA) IN CONSTRUCTION APPLICATIONS

In the United Kingdom the creation of the Central Electricity Generating Board (CEGB) in 1948 gave responsibility for the development of power infrastructure and delivery to one monopoly supplier. This provided the opportunity to develop a coherent and country-wide strategy for the management of coal combustion products. The CEGB developed an in-house research programme and through its portfolio of major construction projects had an outlet to specify and test the performance of its material. In particular the example of using PFA in mass concrete dams was considered, and following research at the University of Glasgow, the practice was adopted for construction of the Lednock, Clatworthy and Lubreoch Dams. Subsequently, it has found uses in numerous cementitious applications including grouts, block manufacture, road sub-base and road-base construction, etc.

PFA has been successfully used as a fill material for many years with the first recorded use in the UK being in 1952. Again, there was a considerable amount of research done in the 1950’s and 1960’s, giving PFA credibility as an engineering material. It is acknowledged to have benefits of low density and high shear strength, which have been instrumental in developing its wide acceptance as a fill material.

Currently about 55% of the PFA produced within the UK is utilised, with the balance used for land reclamation or being landfilled. Even though PFA has such a long history of successful use and there are no recorded environmental problems, there is increasing interest by environmentalists in the impacts of these materials.

THE CHEMISTRY OF PFA

Around 60% to 90% of PFA is present as an amorphous glassy material composed of silica, alumina and iron oxides, with other metals present in smaller quantities, as shown in Table A, which is taken from a variety of sources. The constituents, apart from the glass, that are of most significant to the mechanical properties of PFA are calcium oxide (lime) and sulfate.

Table A – Typical oxide analysis of PFA

Element	**Typical range of values for PFA**
Silicon (% as SiO_2)	45 – 52
Aluminium (% as Al_2O_3)	24 – 32
Iron (% as Fe_2O_3)	7 – 15
Calcium (% as CaO)	1.1 – 5.4
Magnesium (% as MgO)	1.2 – 4.4
Sodium (% as Na_2O)	0.8 – 1.8
Potassium (% as K_2O)	2.3 – 4.5
Titanium (% as TiO_2)	0.9 – 1.1
Chloride (% as Cl)	0.005 – 0.02*
Phosphorus Pentoxide (P_2O_5)	0.09 – 0.65
Loss on ignition (%)	3 – 20
Sulfate (% as SO_3)	0.35 – 1.7
Free calcium oxide (%)	<0.1 – 1.8
Water soluble sulfate (g/L as SO_4)	1.3 – 4.0
2:1 water solid extract pH	9 – 12
* Chloride may be up to 0.3 % for PFA conditioned with sea water	

When water is added to PFA, it initially has a low pH as the sulfate deposited on the surface of the particles is brought into solution as sulphuric acid. This is a transient situation and, after a short time, the pH rapidly rises as calcium is leached into solution. The pH is typically 8 to 11 for PFA, although the pH for those ashes with higher free calcium oxide contents can rise to 12. Only a very small quantity of free calcium is required to achieve the higher pH. For lagoon ash or pond ash, as most of the water-soluble material that influences pH has been washed out of PFA, the pH is lower, typically around 9.

The calcium content of PFA means that most of the sulfate is present as gypsum, which has a limited solubility and will precipitate out in the compacted PFA. The sulfate level of lagoon PFA is usually very low as the majority of the sulfate is washed out by the transport water. Other water-soluble materials are also removed in the process. Therefore, the sulfate content of lagoon ash is typically less than 0.1 g/L.

TRACE ELEMENTS IN PFA

Typical trace elemental analyses are shown in Table B, which demonstrates that other elements are present in only small quantities, less than 1 % of the total. The values quoted are generally in agreement with other quoted values[1,2].

Table B – Solid phase trace element analysis
Typical ranges from UK sources of PFA.

	Typical range of results
Arsenic	4 to 128
Boron	5 to 310
Barium	0 to 36,000
Cadmium	<1.0* to 4
Chloride	0 to 2,990$^+$
Cobalt	2 to 115
Chromium	33 to 192
Copper	33 to 474
Fluoride	0 to 200
Mercury	<0.01* to 0.61
Manganese	103 to 1,555
Molybdenum	2 to 81
Nickel	35 to 583
Phosphorus	372 to 2,818
Lead	<1* to 976
Antimony	1 to 325
Selenium	<1 to 162
Tin	<10 to 1,847
Vanadium	96 to 1,339
Zinc	49 to 918

All expressed as mg/kg
* Indicates below the limit of detection
$^+$ Includes seawater conditioned PFA

LEACHABLE COMPOUNDS WITHIN PFA

Over a period of many years, a considerable amount of work has been carried out to determine the leaching characteristics of PFA. PFA is widely reported as having very low solubility. This is because most of the solid elemental inventory is held within the largely insoluble “glassy” alumino silicate matrix. Typically, ~2% of PFA is found soluble and the eluates are dominated by calcium sulfate (gypsum), which is a naturally occurring compound found in many soils, with lesser contributions from sodium, potassium and chloride ions. Most of the metals and metalloids present in the ash are either retained in the glass beads or firmly adhered to them, resulting in a very low leaching potential. PFA is also alkaline with a pH of typically 9 to 12, which materially assists in retaining metals.

Many other compounds are believed to be present as oxides, sulfates and chlorides in the enriched surface layer of the PFA particles. These may be released and precipitated as secondary solids or adsorbed onto the solid substrate depending on their solubility limits. Only a few elements are fully soluble in the initial leachate because of their limited solubility at high pH.

Other than the calcium referred to above, the most mobile metallic element is boron, which exists primarily as borate. Boron exists as a vapour at the temperature of molten ash, hence its availability in PFA. When the ash solidifies, the boron condenses on its surface rather than being incorporated in the glass matrix. Weathering may eventually mobilise up to 50% of any boron and molybdenum together with 25 to 30% of the arsenic and selenium in the PFA. The actual behaviour of these and other elements appears to be specific to the source of ash and the total amounts present.

The inorganic composition of PFA is dependent upon the mineral matter present within the coal that is fired in the furnace. The organic compounds are influenced by the effectiveness of combustion and cooling that has taken place.

In many UK power stations, surplus PFA is transported as slurry in pipelines and hydraulically placed in lagoons or ponds. The slurry typically contains 15 to 30% ash. This is allowed to sediment out under gravity in a lagoon, resulting in stratification of the particle size distribution in the lagoon both horizontally and vertically. During this process a large part of the water-soluble material present in the PFA is dissolved and is removed along with the decanting water. As lagooning the ash is not a 24-hour process, for much of the time clean water is passed down the pipelines. This is done to control scaling and it further dilutes the water-soluble species within the lagoon.

The lagooning process removes most of the soluble species, excepting those limited by solubility constraints or by diffusion within the alumino silicate matrix. Almost all of the water-soluble elements found in PFA show a gradual decline after being lagooned. The remaining soluble material consists of the sulfate and chlorides of alkali metals plus trace levels of metallic elements that can form soluble anions at high pH.

The buffering effect of PFA reduces the leaching potential. Should the high buffering capacity ever be exhausted some of the trace elements can be expected to become more mobile. However, the low permeability and reserve alkalinity of PFA is such that only a few centimetres of a deposit, embankment, etc is likely to be affected by the acid media type normally present in the environment. The risk of a mass release of these trace elements is correspondingly small.

INORGANIC COMPOUNDS

There is only a small fraction of the constituents that is present on the surface of PFA and that are leachable in water. Typical data obtained from routine analysis are shown in Table C; the extraction is based on results from both the German standard DIN 38414-S4[3] (10:1 water/solids ratio) and National Rivers Authority (NRA) extraction test.

Table C – Leachates found using the DIN 38414-S4 and NRA extraction methods.

Typical range of leachable elements for UK PFA (mg/L except pH)			
Aluminium	<0.01* to 9.8	Manganese	<0.01*
Arsenic	<0.1*	Molybdenum	<0.1* to 0.6
Boron	<0.1* to 6	Sodium	12 to 33
Barium	0.2 to 0.4	Nickel	<0.01*
Calcium	15 to 216	Phosphorus	<0.1* to 0.4
Cadmium	<0.04*	Lead	<0.01*
Chloride	1.6 to 17.5	Sulfur	24 to 510
Cobalt	<0.01*	Antimony	<0.01*
Chromium	<0.1*	Selenium	<0.01* to 0.15
Copper	<0.01*	Silicon	0.5 to 1.5
Fluoride	0.2 to 2.3	Tin	<0.1*
Iron	<0.1*	Titanium	<0.1*
Mercury	<0.001*	Vanadium	<0.01* to 0.5
Potassium	1 to 19	Zinc	<0.02*
Magnesium	<0.1* to 3.9	pH	7 to 11.7

Notes: The above data include a seawater-conditioned sample resulting in higher chloride values. The Boron content may also be increased.

* Indicates below detection limit.

From the data, it can be seen that the major water-soluble constituents are calcium and sulfur (usually present as sulfate). There are smaller amounts of sodium and potassium, and traces of chloride, magnesium, aluminium and silicon. If it is assumed that all the water soluble calcium, sodium and potassium is present as hydroxide, ignoring the sulfate or chloride, then the total water soluble hydroxide, based on the highest values from Table C would be 2.1% (m/m). However, calcium hydroxide would make up approximately 2.0%; the others would represent less than 0.1 %. In all instances quoted the calcium is very dominant with sodium and potassium present in very small quantities in comparison.

The following features should be considered when evaluating the actual environmental impact potential represented by these results.

- Where the material is to be used in the form of compacted engineering fill with a permeability of around 10^{-7}m/s, the amount of leachate that can be produced is very small indeed. Risk assessment models are specified by the Environment Agency aimed at establishing whether an environmental impact has the potential to cause significant harm. These models are very conservative for PFA which, owing to its insitu permeability does not create an adequate pathway to leach minerals and transport them to the receptor.
- Leachate tests are often based upon agitation of a PFA and water mixture. This is not representative of field conditions where water is usually shed from the PFA by the design drainage route or at worst steadily percolates through the mass. Column tests are more likely to give a laboratory representation of the worst field conditions.

- The leachate test uses distilled water and dry ash. Under these circumstances, the pH of the liquor first falls as the sulfates are taken into solution. The result is that pH can fall to around 4 in the distilled water based solution for a period of time, until the effects of the alkaline constituents begin to take effect and drive the pH alkaline. On a power station, the ash is mixed with river water either to condition it or to produce slurry to transport the ash to a disposal site. The river water is buffered and somewhat alkaline that does not allow the pH to fall and cause mobilisation of metals on the scale represented by a leachate test.
- It has been widely reported that the available materials in PFA are rapidly depleted and that successive leaching reduces concentrations significantly. However, owing to the lack of a pathway between the leachable minerals and the receptor the release of minerals would be extremely slow under field conditions.

In summary about the inorganic compounds in PFA it is noted that:

1. The majority of the ash is present as an alumino-silicate glass;
2. Most elements are present in very small quantities and are largely encapsulated in the glassy material;
3. Typically, less than 2% of the PFA is water-soluble; calcium and sulfate constitute the majority of the water-soluble fraction. There are smaller amounts of sodium, potassium and, in low pH leachate, magnesium;
4. The pH is mainly determined by the water-soluble calcium and sulfate producing an alkaline environment.

ORGANIC COMPOUNDS

PFA contains very little organic material, other than elemental carbon. Combustion in the power station furnace, which has peak temperatures in excess of 1250C, will remove and break down most organic compounds present in the original coal. There are no synthetic organic compounds such as pesticides etc. There is usually a small amount of elemental carbon in PFA, but nothing that will undergo organic degradation. Consequently, a deposit of PFA does not produce gas from biodegradation. The elemental carbon is partially activated and capable of absorbing some deleterious compounds, such as polycyclic aromatic hydrocarbons (PAH).

Organic compounds: Polycyclic Aromatic Hydrocarbons in PFA

PAHs can result from the incomplete combustion of fuels such as wood, coal and oil. They are widespread in the environment, largely because of inefficient coal combustion during the years prior to the development of pulverised coal fired furnaces. Metabolic transformations, by aquatic and terrestrial organisms, result in carcinogenic substances[4]. The most potent PAHs are benzofluoranthenes, benzo[a]pyrene, benz[a]anthracene, dibenzo[a,h]anthracene and indenol[1,2,3-cd]pyrene.

The total PAH concentration in PFA has generally found to be less than 0.5 mg/kg, due to the binding of PAHs to PFA particles, which is less than 1% of the lower threshold of 50mg/kg – the total concentration requirement in the Environment

Agency “Interim Guidance on the Disposal of Contaminated Soils - Table 1”. However, more recently the Joint Environmental Programme[6], using more efficient techniques, reports total PAHs in PFA of up to 25mg/kg, though more than half of the samples containing less than 10mg/kg. These values are still significantly lower than the threshold value.

The potential strong binding of PAHs to PFA, which is reflected in the problems with extraction, is consistent with the behaviour of soils. This binding dictates much of the environmental behaviour of PAHs, including their low availability for plant uptake and minimal groundwater leaching problems. PAHs are only sparingly soluble in water, the solubility decreases with increasing size of molecule, for example naphthalene with 2 benzene rings has a solubility of 32 mg/L whereas benzo[a]pyrene with five rings has a solubility of 1.6×10^{-3}mg/L.

Although there has been a significant amount of work on PAHs arising from combustion of coal, most effort has been focussed on airborne particulate matter. PAHs will undergo photo-degradation and are therefore thought to have a limited life span in the atmosphere. Naphthalene, Phenanthrene, Acenapthene and the other compounds which are in greater proportions in PFA are in general the least toxic PAHs and subject to rapid adsorption and reasonably rapid degradation. The more toxic PAHs and the more slowly degrading substances either are not detected or present at very low concentrations compared to Naphthalene etc.

PAHs all adsorb readily and strongly onto other organic materials such as soils. In aerobic conditions, they are degraded with half-lives from a few days to a few years. Degradation is particularly rapid (half-life in hours) if the compounds are exposed to UV radiation from sunlight. Thus even though the concentrations of PAHs are fully compliant with standards, and the very low permeability mitigates against leachate production, the minute amount of PAH will be locally adsorbed and degraded and cannot affect the broader environment.

In summary of PAHs in PFA it is noted that:

- Most work has been done on PAHs associated with particulate matter that is released to the atmosphere. Little work has been done on water-borne PAHs.
- There are traces of PAH present on PFA, typically up to 25mg/kg, although the difficulty in recovering PAHs from PFA means that the amount detected may be significantly lower.
- PAHs, particularly those with high molecular mass, tend to be adsorbed onto the surface of the PFA and recovery of the adsorbed PAHs is very difficult.
- PAHs have an affinity for particulate matter, especially carbonaceous matter and dissolved PAHs can be removed from solution by PFA.
- Due to the low solubility, the leachate from PFA contains low concentrations of PAHs.
- PAHs adsorbed onto PFA tend to be resistant to photo-degradation, although it is possible that PAHs not exposed to light can still undergo oxidation.

Organic compounds: Phenols

An assessment of the level of Phenols in the leachate from three UK power plants found all results to be below the level of detection. The limit of detection meets the UK drinking water standard limits and is 20% of the UK standard set for bathing waters. It is notable that the UK drinking water standards have been fixed to avoid the production of compounds with chlorine in the drinking water treatment process and not because of the effects of phenols at these very low concentrations.

The fate of phenols will be broadly similar to PAHs except that the half-life of most phenols is considerably less than the half-life of PAH. They are present in very low concentrations that will be retained in ash deposits and released very slowly, if at all. There will be some slow “in deposit” degradation and the minute amount of phenols, which could be released, will be rapidly adsorbed and degraded in the environment. Since the source concentrations are undetectable and rapid adsorption or degradation will reduce the concentrations, it is therefore inconceivable that phenols can cause pollution.

CONCLUSIONS – LEACHABLE MATERIALS WITHIN PFA

When used in structural fill applications PFA has very low permeability, which means that there is very little passage of water through it and very little potential leachate. Most trace metals are held in the alumino silicate matrix and are not available to leach. A deposit of PFA is alkaline which further aids retention of metals. PFA has almost no biodegradable organic material and produces no gas as a product of such degradation. When fully mixed with river, as in an ash slurry system, the pick up of trace elements is substantially less than the values obtained in a standard leaching test.

DIOXINS IN PFA

Dioxins are usually associated with the incomplete combustion of material containing chlorine and as such are commonly associated with the ash from municipal waste incineration, but can be found in small traces in soils. Dioxins levels in PFA are consistently very low, due to the low chlorine content of coal combined with the high temperatures found in the furnaces of power stations. Dioxins are ubiquitous and are present in a wide range of soils and although they can be persistent, they rapidly decay when exposed to light.

Work by the Central Electricity Generating Board (CEGB)[7] in the 1980’s examined the dioxin levels in eighteen PFA samples from a range of sources for dioxins from the tetrachlorinated to the octachlorinated. The findings were that the levels were very low, typically less than 25 ng/kg, with levels of 2, 3, 7, 8-TCDD less than 2 ng/kg in all but two samples.

Subsequent to television programmes broadcast in the UK during July 2001 and December 2001 that suggested that some forms of ash had high dioxin levels, the UK generating industry in England took samples of pulverised fuel ash (PFA) and furnace bottom ash (FBA) from seven coal-fired power stations. These samples were tested at accredited laboratories for the seventeen dioxins and furans chlorinated at the 2,3,7,8 positions. All of the results show levels of dioxins and furans in PFA to be in the range 0.049ng/kg to 2.4ng/kg I-TEQ. JEP reports[8] on further testing carried out on PFA and FBA and concludes that the dioxin content of all samples was typically less than 20ng/kg I-TEQ. Samples of siliceous sand were submitted for test as ‘method blanks’. These method blanks contained up to the same amounts of dioxins as the PFA and, therefore, it is considered these results are insignificant. These values are close to or below detection limits and are similar or lower than background levels typically found in soils and many other products.

In summary about dioxins levels in PFA

- Dioxins are typically less than 20ng/kg I-TEQ.
- Although dioxins are present in PFA, the levels are very low and similar to or less than the background levels found in typical soils. Accordingly, PFA is no more hazardous than soil.

RADIATION FROM PFA

Radiation from PFA results from the concentration of natural minerals within the coal; e.g., the carbon fraction is removed when fired. The natural radioactivity of coal and of the ash results mainly from the radio nuclides from the decay series of uranium and thorium as well as potassium 40. There is no significant increase in the radioactive composition as nothing is added and no process used that could cause such an increase. Potassium 40 decays into calcium 40 or argon 40, both of which are stable nuclides that will not decay further. From PFA the ^{40}K content of potassium is only 0.012% and from the radiation viewpoint ^{40}K has little significance.

In 1986 the CEGB commissioned a comprehensive study of the emissions from UK PFA as reported by Green[9]. The project included PFA, building materials made using PFA and field studies of radiation from buildings and ash disposal sites. Table D summarises the data from this work.

Table D – Summary of estimates of annual effective dose equivalents from PFA (Green)

Situation	**Annual effective dose equivalent – µSv**					
	Normal Ground			PFA disposal site with 500mm of soil cover		
Indoors	From γ	From R_n	Total	From γ	From R_n	Total
All brick dwelling	740	260	1000	750	360	1110
Heavy block dwelling	700	290	990	710	400	1110
Light block dwelling	530	340	870	540	440	980
Outdoors						
Workers such as farm or disposal site labourer (2000 hrs p.a.)	56	57	110	70	60	130
Members of the public (500 hrs p.a.)	14	7	21	18	8	26
Inhalation of re-suspended dust (8,760 hrs p.a.)			11			
NB: Values rounded to two significant figures						

Green concluded that:

- The incorporation of PFA in building materials did not result in increased radiation exposure above that from the use of traditional clay bricks.
- Aerated concrete blocks reduced the annual collective dose by about 2%.
- There was no significant radiological hazard to workers or members of the public from restored or working ash disposal sites.
- There was a potential risk of increased radon exposure from buildings built of ash disposal sites. This risk could be removed by simple preventative measures at the design stage.

More recently, The International Union of Producers and Distributors of Electrical Energy (UNIPEDE) produced an expert group report[10] that reviewed the various features of PFA including the radiological properties. They summarise the radioactivity from PFA around Europe as in Table E.

Table E – Radioactivity in PFA in Bq/kg (UNIPEDE)

Reports from	PFA from	U-Series			Th-series		
		Min	Max	Average	Min	Max	Average
Germany	Germany	93	137	119	96	155	121
	UK	72	105	89	3	94	68
	Australia	7	160	90	7	290	150
	Poland			350			150
Italy	Italy	130	210	170	100	190	140
Denmark	Denmark	120	210	160	66	190	120
Sweden	Sweden	150	200		150	200	
Belgium	Belgium	112	316	181	88	277	150
Spain	Spain	80	106	91	77	104	89
Germany				189			118
Czech rep.	Czech rep.	35	190	129	62	142	90

They refer to the World Energy Conference Report that suggests an average specific activity concentration of 200Bq/kg. It is clear from the table that some countries may have some difficulties with such limits, especially those from Eastern Europe. However, UK PFAs are the lowest reported.

HOW DOES THIS TRANSLATE TO REAL APPLICATIONS?

While the above data clearly show that the potential for leachates and radiation from PFA is very low, this is no substitute for measurement of the release of compounds from real applications. In 2000 the UK Quality Ash Association commissioned the University of Nottingham to examine the leachates and radon emissions from PFA embankments constructed between 1967 and 2000. In addition a natural sand embankment was tested in a similar manner.

In this project, Arnold, Dawson and Muller[11] took samples of groundwater and surface water adjacent to and from the up flow side and down flow side of the embankments. All leachates were tested by an independent commercial laboratory. Radon and Radium measurements were taken directly from the embankments by drilling into the embankments and analysing the air using a ‘sniffer’ device.

The overall conclusions of Arnold, Dawson and Muller’s paper are:

- Concentrations of contaminants in ground water were all rather low.
- In the vicinity of three of the five embankments studied some contaminant concentrations greater than that normally permitted for drinking water quality were found.

- Five determinands (out of 31), which may be attributable to PFA, gave values above normal drinking water quality levels on at least one occasion. These were Magnesium, Selenium, Potassium, Sodium and Sulfate.
- Of the five contaminants listed above, only Potassium, Sodium and Sulfate appear to be of any significance. Agriculture and traffic are much more credible sources for all the contaminants which appear at high concentrations, than is the PFA. This is borne out by the fact that one non-PFA site investigated yielded similar concentration levels to the PFA sites.
- On the basis of this investigation, it is very unlikely that PFA is a significant cause of contamination of groundwater at a level of concern to the environment.
- No Radon was detected anywhere at levels above the most onerous intervention level.
- The highest Radon levels detected were in the PFA pore space. Radon levels in air adjacent to the PFA were extremely low.
- The age of the PFA and the PFA source do not appear to have a noticeable influence on the levels of contamination or of Radon emissions.
- On the basis of this investigation, PFA in embankments poses no hazard to health.

CONCLUSION

It is clear from various sources of information that PFA does not represent any significant environmental risk[12] when used as a fill material, either from leaching or radiation. Even though such findings have been proven repeatedly over the many years of use there is lack of acceptance within the environmental science community that coal combustion products can be used in the construction market as freely as naturally won aggregates.

In the United Kingdom PFA has for many years has been exempt from waste management licensing when it is sold for beneficial applications. The Environment Agency is once again challenging its use and seeking to increase the controls over its application. The burden of the title ‘waste’, coupled with the general perception that anything that is a ‘waste’ cannot be environmentally safe, has lead to the unsubstantiated denigration of the material. However, PFA is safe and can be used for unbound applications without risk to the environment and reducing the environmental impact of quarrying large volumes of natural aggregates.

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