

# **QUARRIES REINFORCEMENT WITH STABILIZED BOTTOM ASHES**

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## **SUMMARY**

With the new developments of the Beaulieu District in Caen (France), the reinforcement of the underground mine workings appears to be necessary : these mines have been worked since the XIth century and are now beginning to fall in. In place of traditional material (scouring sand for example), they are filled in with a specific mortar, prepared with inertized bottom ashes, developed for this use by INERTEC.

Iron has first to be removed from the bottom ashes, coming directly from the MSW incinerator. Bottom ashes are then passed through a sieve, in order to obtain an homogeneous material, and stored on a watertight area. Sieved bottom ashes are mixed with water and reagents, as defined in INERTEC process in order to have a pumpable product, and then pumped to mine workings. Final material features are tested by inner and outer controls, according to the french regulation.

Besides, a specific study has been begun by INERTEC and ADEME on the long term behavior of inertized bottom ashes in underground mine workings, in application of the X 30-407 french methodology, which first results are given in this paper.

**Introduction**

In 1995, France published its first standard about long term leaching behavior. It is a guideline which describes the methodology to assess the long term behavior of waste in a given scenario.

Concerned about environmental protection, INERTEC, in collaboration with ADEME, has decided to adopt this new step to the innovating operation of inertized incineration bottom ashes utilization as mine backfill material.

Before presenting the first results of this operation, we would like to introduce the French regulation context.

**1. First laws about waste**

**1.1 How to manage waste disposal in general**

With its first law about wastes (1975) and a specific law about classified plants (1976), France owns an efficient legislative systems based on the principle of producer's responsibility and best available technology to manage their waste from production to disposal.

Rapidly, a complete network of collective disposal plants for municipal and industrial waste is created.

Judged heavy at first, these new laws contribute to the development of a new industry whose efforts are increasing.

On July 13, 1992, the 1975 act is updated and new

principles for waste management are integrated :

- the ultimate waste (i.e. waste which cannot be reused, recycled or treated in the current technical and economical conditions) alone has to be stored,
- reduction of waste production and / or waste noxiousness,
- waste valorization,
- limitation of waste transport in terms of distance as much as duration.

On December 18, 1992, specific regulations about industrial waste landfill dumping confirm for industrial waste the great principle of the 1992 act and modify noticeably these landfilling conditions.

**1.2 Particular case of bottom ashes**

On May, 1994, a French Ministry Circular specifies criteria regarding incinerator bottom ashes for landfill dumping and reused in road basement.

Three classes of bottom ashes are defined :

- Class V, low leachable fraction : this class of bottom ashes can be reused directly but are subject to a few restriction concerning contact with water,
- Class M : intermediate bottom ashes, they are reusable after maturation or treatment (12 months maximum) provided after this the criteria for class V are respected.

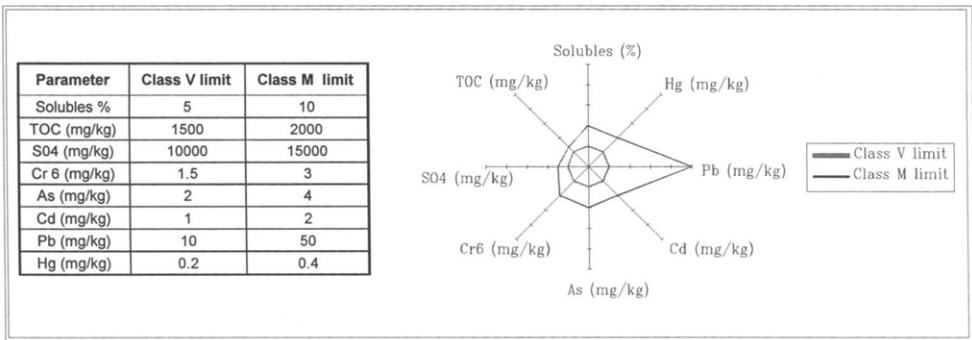


Figure 1- Regulation Limits for Domestic Refuse Incinerator bottom Ash

- Class S : High leachable fraction, their disposal must be in class II landfills.

The test actually used for pollution potential is a compliance test. It consists in three successive leachings after grinding the ash to 4 mm size, using standard X 31-210 test procedure. Leachate pollutant contents are compared with the limits specified in the ministry circular (see fig. 1).

## 2. An avoidable evolution

These new conditions of waste disposal are not defined on a notion of impact on environment. It is probably because of the lack of scientific data in this field.

This lack of scientific data was often made up for by the development of technologies improving always more disposal waste.

However it seems today that this approach of best available technology can not constitute the only answer in term of objectives and level to reach as far as environmental production is concerned.

In this content, ADEME (the French Agency for Environment) has been committed for over 5 years with several partners, in many researches aiming at the integration of « impact logic's » in regulations. This means that criteria fixed to choose the best disposal means will be based on reliable tools of measurement and assessment of the real impact of waste on environment.

It was therefore for ADEME the obvious thing to accompany the innovating operation of Caen.

## 3. Application in backfilling BEAULIEU mine workings

### 3.1 General description

The CAEN underground workings (FRANCE), several million cubic meters in extent, have been in use since the 11th of lime carbonate rock. There was no precise legislation and

each mine was worked without controls, frequently to the detriment of the most elementary safety rules. Pillar widths may vary from 3m to 1m on a side, from one room to the next. Each mine grew differently over time with different pillar numbers and sizes and different faulting affecting the roof. Pillars that were too few in number or too small in size cracked and sometimes collapsed, bringing the roof down with them. Periodical inspections by the Caen mines department indicates that the competent overlying strata of massive limestone have so far prevented ground level subsidence.

The land was mainly agricultural, i.e. without building loads and only intermittently occupied, and raised no safety problems.

However, plans to develop the Beaulieu area (22 hectares) made it necessary to provide support to all the workings to prevent future damage to buildings, roads and buried services, since static loads applied by buildings and static/dynamic loading from roads would put added stress on mine roofs. The support work was awarded to SOLETANCHE, with a range of support designs to suit pillar cracking and ground loads. The workings under the planned Georges Pompidou road will be the most exposed area because of severe static and dynamic loading : it had also to be backfilled. The same method has been used for parts that are too dangerous for men to enter. At the very beginning of the workings, SOLETANCHE suggested to use inertized bottom ash mortar for backfilling. Inertization process design, quality control specifications and control tests have been conducted by INERTEC.

### 3.2 Development of bottom ash mortar

The two categories of pollutant found in incinerator bottom ashes are salts and heavy metals.

Salts consist mostly of soluble sulfates which must be changed to insoluble forms within the mortar of inertized bottom ashes.

The most important of the heavy metal pollutants is lead, some of which may enter ash leachate in dissolved form.

Developing incinerator bottom ash as a stopping material involves :

- formulating the correct mix of reagents to fix pollutants,
- obtaining the required rheology.

For the specific application of the BEAULIEU mine working backfilling, the basic INERTEC formulation for producing a inertized mortar from incinerator bottom ash had to be adjusted to obtain a pumpable mortar able to be grouted from the stationary inertization unit to the mine working. The bottom ashes aimed for this application were produced by the municipal solid waste incinerator of Caen and were classified as class M because of solubles, lead and total organic carbon in the leachate. The mix formulation was also defined in laboratory to have sufficient strength (and pumpability) and comply with the class V limits.

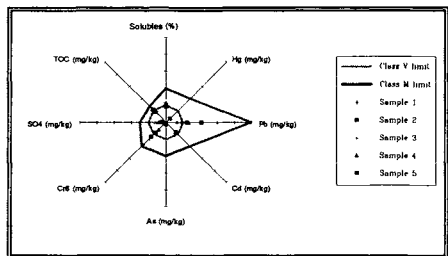


Figure 2 : Leaching test results before treatment

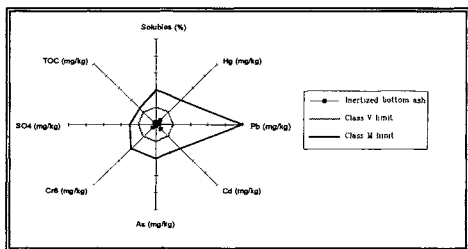


Figure 3 : Leaching test results after treatment

Then compliance tests were required to validate the laboratory formulation in terms of pumpability, strength and chemical retention of pollutants as required by the Owner (City of Caen) and the supervisory agencies. No work was allowed to begin before validation of the results obtained from these tests by the monitoring panel set up by the supervisory agencies. The tests consisted of producing the inertized bottom ash mortar in full-size plant and checking (mainly from samples) that it complied with the expected treatment : suitable rheology to pump the inertized bottom ash mortar from the stationary inertization unit to the most remote backfill site (about 600 m) and respect of class V limits.

3.3 Full-Scale Production

A full-scale production plant was set up on the Beaulieu development site over the workings to be supported. It is shown schematically in the following figure.

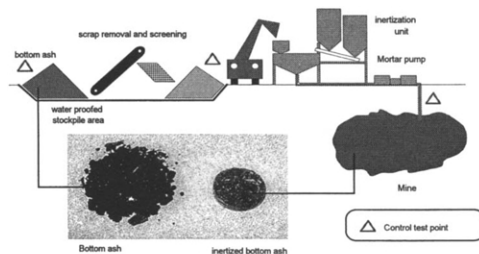


Figure 4 : Treatment plant

SOLETANCHE instigated a Quality Assurance Plan for the duration of the contract (one year from february 1996) to control impacts from the work on the environment.

Untreated bottom ash were delivered directly from the incinerator. Each lorry load was sampled, and, as well as recording color, smell and other visual aspects, the site laboratory ran a quick leaching test to determine pH and solubles content. This test ensures that the load is not

category S material : during all the work, measured solubles were between 4% and 7%, well below the class M 10% limit. Besides these quick tests, other tests were performed separately, internally and externally, on a sample taken by the county laboratory.

After removing metal scrap, the bottom ash was screened to produce an even grain size and stockpiled on a watertight floor. Rain and wash water were collected in a pond and recycled as process water in the ash inertization unit. No water has been discharged off-site. The water table (10 m below the lowest level of the mine workings) was monitored by taking samples from three piezometers around the site.

The backfilling work was then made by phases.

The sorted and screened ash were fed into the mixer with the mix water and inertization reagents. After a few minutes mixing, the mortar was discharged and pumped directly into the mine. The mortar set into a low-permeability solid that will not react with the environment. The quality of the final material was monitored internally (Quality Assurance Plan) and by an outside body for each separate section of the work. The Quality Assurance Plan also covered noise and odors, which may seriously inconvenience nearby residents throughout the duration of the job. As with the analytical tests, these nuisances were monitored separately, by site and by outside bodies.

The Beaulieu mine stopping job can be summarized in a few figures:

Daily capacity of screening unit : 120 t/day

Daily capacity of inertization unit : 400 t/day

Duration : 12 months (february 1996 to february 1997)

Volume of workings to be backfilled (on the Beaulieu area) : 40,000 m<sup>3</sup> (equivalent to the annual ash production from Caen municipal solid waste incinerator plant).

#### 4. Assessment program : application of the X30-407 methodology

##### 4.1 Description of the study

The aim of the study is also to evaluate the leaching behavior of inertized bottom ashes in the Beaulieu mine workings. According to the X 30-407 methodology guideline, the program consists of different steps :

##### Description of the scenario

Previous studies have shown that mechanical and geotechnical conditions can be neglected in the first step of the methodology application : changes may principally have a influence on the exchange with the leachant. Biological alterations will probably be very limited because of pH conditions ( $\text{pH} \approx 12$ , generally harmful for bacteria development) and air lack. Hydrogeological and climatic conditions will also be the most important factors in the leaching behavior evaluation. The scenario of inertized bottom ash disposal can be described by the following diagram :

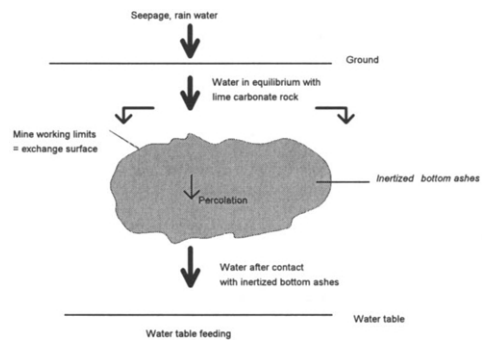


Figure 5 : disposal scenario

General informations have been collected from previous studies (from mine working for example) and meteorological office. Seepage rate can be estimated from rain and temperature measures. The soil above the inertized mortar

will be considered as saturated so that seepage water comes directly on the inertized mortar.

*Description of the waste*

Some properties of the inertized bottom ashes have been already studied in the laboratory test program before the beginning of the full-scale work. They needed to be completed for the long term leaching evaluation :

- characterization of bottom ashes : chemical variability according to quick leaching test results, grain size distribution, total chemical composition...
- characterization of inertized mortar : chemical variability according to leaching tests results, strength variability to confirm the structural durability (already demonstrated on a few samples), permeability and porosity to determine the water transport main regime, total chemical composition...

*Experimental determination of leaching behavior*

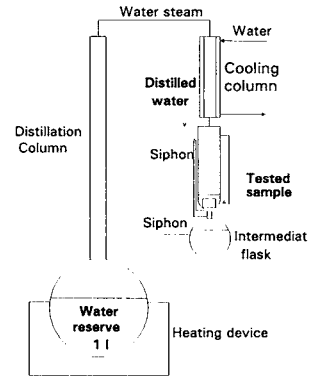
This step consists of determining the relevant parameters influencing the leaching behavior :

- nature of the leachant in the specified scenario : water after contact with carbonate lime rock (through analysis of water collected in the Beaulieu mine workings and pH stat tests in laboratory on carbonate lime rock samples)
- physical parameters : they will be neglected in the first step of the methodology application because temperature and moisture variations are very limited in the working mine area (10 meters below the ground level).
- mechanical and geological parameters will also be neglected (structural integrity of the mortar is already checked in a previous step of the study).

The leaching behavior will also be studied through long term leaching tests (several months) with modified "soxhlet" equipment (see fig. 6). This test consists of putting a waste

monolithic sample to a continuous flow of distilled water, made by evaporation of a constant water reserve. The original equipment has been modified so that water in contact with the sample is at room temperature.

*Modeling of leaching behavior* , thanks to long term leaching tests.



**Figure 6 : modified "soxhlet" equipment**

*Experimental validation of leaching behavior* with in situ results. A mine working room has been chosen in agreement with the city of Caen and equipped in order to follow the potential release of pollutants from inertized bottom ashes during several years :

- horizontally laying of a drainage material on a first layer of inertized bottom ash (the chosen room was already partly backfilled and the set mortar laid about 2 meters from the roof of the mine working) to collect percolation water,
- vertically laying of a drainage material, along the wall, to collect runoff water.

The room was then completely backfilled so that the drainage material is now in contact with the inertized bottom ash mortar. The drainage material collects water and directs it to collecting pipes (one for each system) which run across the room walls and arrive in the next room.

An additional piezometer with taking of cores has been dug after the setting of the mortar in the chosen room. Four piezometers will also be sampled at regular intervals to detect a potential release from the mortar.

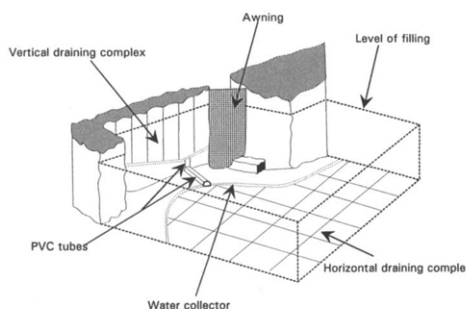


Figure 7 : in situ instrumentation

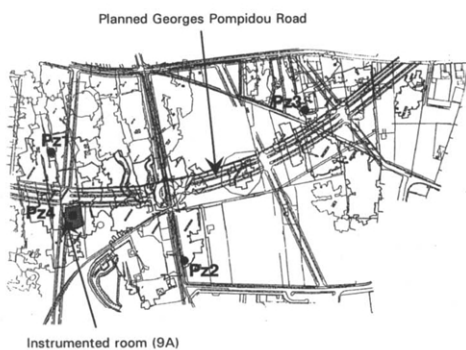


Figure 8 : site geography

## 4.2 First results

### 4.2.1 Laboratory tests

Non treated bottom ashes have been sampled weekly during several months, in order to follow the leachate variability and to determine an average leachate concentration. Arsenic, chromium, mercury and cadmium are seldom detected. Variability of pH of leachates and water content is not very important. Lead, total organic carbon and solubles are

always below the class M limits and even sometimes below the class V limits.

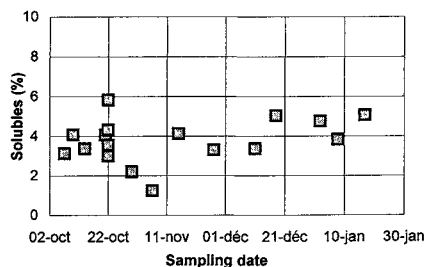


Figure 9 : Solubles variability

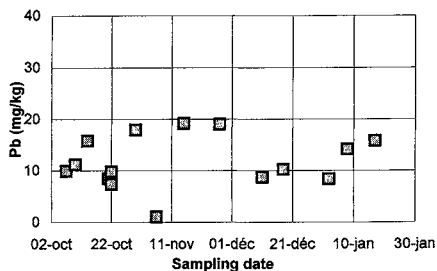


Figure 10 : Lead leachate content

An average leachate composition would be the following, with arsenic, chromium, cadmium and mercury under the ICP detection limits :

Parameter	Leachate content (X 31-210)
Water content (%)	81.1%
Solubles (%)	4.8%
SO <sub>4</sub> (mg/kg)	1988
COT (mg/kg)	1187
Pb (mg/kg)	11.4

Table 1 : Average leachate composition

Grain size analysis shows the apparent heterogeneity of the material. Largest grains are mostly glass particles and unburnt residues (paper...). Glass particles will be considered as chemically inert for the leaching behavior

study. Chemical analysis do not allow to determine any clear correlation between heavy metal content and particle size. Calcium seems yet slightly more concentrated in smallest particles.

Concerning the mechanical properties of inertized bottom ashes, two parameters have been parallel followed with curing time : compressive strength and water permeability. The compressive strength increases between 28 and 90 days while the water permeability decreases. After 90 days, water permeability is about  $7.10^{-9}$  m/s and the compressive strength seems to reach an asymptote (see fig. 11).

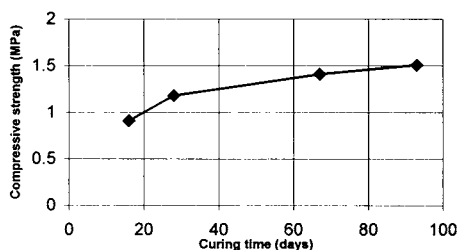


Figure 11 : compressive strength evolution

According to the french leaching test, heavy metals are not on a soluble form in inertized bottom ashes : they are not detected in leachates. The total content in the mortar is also very low :

Heavy metals	Total content (mg/kg)
As	< 17
Cd	6.6
Cr	147
Pb	535

Table 2 : inertized bottom ash analysis

Lead has the highest concentration among heavy metals. Major components are silicium and calcium. A part of silicium content comes from glass pieces, which represent the major phase of largest particles in bottom ashes.

Calcium comes partly from bottom ashes (with a pH value higher than 12).

After two months of long term leaching test (total water flow about 170 liters on a sample of 130 cm<sup>2</sup> surface, e.g. ratio liquid/solid  $\approx 22$  m<sup>3</sup>/m<sup>2</sup>), the total extracted concentrations of heavy metals are very low (maximum 1.5% of total content), so that analysis results are often below the detection limit.

A part of extracted heavy metals precipitates in the water reserve (probably as calcium silicate components) and can be only dissolved by fluoridric attack.

The lead extraction diagram shows the total extracted concentration and the cumulative concentrations in the clear reserve water (before precipitate attack). In all leachate samples, concentrations are yet very low, close to the ICP detection limits.

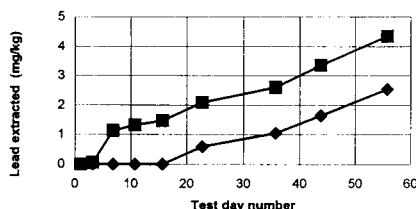


Figure 12 : lead extraction diagram

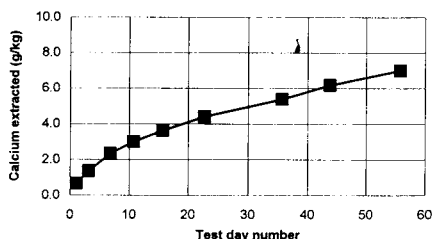


Figure 13 : calcium extraction diagram

Characteristic parameter of hydraulic binders matrix (like calcium) are parallel analyzed to determine the leaching behavior of the material.

The extraction curves can't be assimilated to straight line with a 1/2 slope in logarithmic scales, which would be characteristic of simple molecular diffusion. The leaching mechanisms result from dissolution-precipitation (interactions with the matrix components) and diffusion coupling, which are more difficult to model.

Long term leaching tests are not yet stopped and studies are now going on to realize a modelisation of leaching mechanisms.

#### 4.2.2 In situ results

Water has been collected before the complete backfilling of the chosen room for experimental validation and analyzed to determine the composition of water in contact with inertized bottom ashes. Main components are calcium, sodium and magnesium, with a slightly basic pH :

	Sample 1	Sample 2	Sample 3
pH	8,29	8,02	7,91
Conductivity (mS/cm)	0,807	0,839	0,842
Al (mg/l)	0,33	0,34	0,35
Ca (mg/l)	134,4	133,7	135,3
K (mg/l)	0,34	3,68	3,54
Mg (mg/l)	7,35	7,66	7,67
Na (mg/l)	13,72	18,64	18,31
Si (mg/l)	1,17	1,21	1,2

*Table 3 : site water composition*

Water table samples thanks to piezometers has approximately the same composition.

Concerning the drainage system, no water has been collected by the horizontal drainage material, which suits to

the low permeability measured on inertized bottom ash mortar samples. Two water samples have been collected from the vertical drainage material. After contact with inertized mortar, water has a more basic pH and a higher salt concentration (especially sodium and potassium chloride), but heavy metals concentrations are close to detection limits. Two samples are however not sufficient to make an accurate interpretation : other samples will be analyzed at regular intervals, when rainfall will be high enough to have seepage (unlike in january and march).

## 5. Conclusion

The community benefits from the backfilling operations described, in two ways.

First, there is an economic benefit. The saving on purchase and haulage of borrow material to backfill the workings, and disposal of class II ash from the Caen domestic refuse incinerator plant in landfills, offsets the costs involved in ash re-use for scrap removal, screening and inertization.

There is also a direct benefit for the environment. Re-use of bottom ash frees a commensurate capacity at the Caen landfill for municipal waste that is not fit for re-use. At the same time, it avoids the need to quarry borrow materials resources from the environment.

The assessment study, in application of X 30-407 guideline, will allow to support this original valorization mean, that seems at first a safety recycling way for inertized bottom ashes, according to the leaching exposure.