XXII World Road Congress

Proposed paper for TS1 - C7/C8 Committee – Innovation to improve the environment

Title: Techniques for using household waste bottom ash in road construction

The experience of a roadworks company

Author: Honoré GOACOLOU – Entreprise EUROVIA

18, Place de l'Europe
92565 Rueil-Malmaison Cedex
France

Tel: 33 (0)1 47 16 45 73

Fax: 33 (0)1 47 49 19 70

E-mail: hgoacolou@eurovia.com

In France, the policy of managing waste as part of sustainable development is driving research into ways to recover, recycle and reuse waste. Roads consume large volumes of material and provide opportunities which the road construction industry has explored.

This paper presents the experience of a roadworks company with the use of household waste bottom ash. The document presents the potential benefits of this technique and then discusses:

- Geotechnical and environmental characteristics of household waste bottom ash,
- Problems encountered in some ten years of experience,
- Ways to improve the material geotechnically and environmentally through treatment with hydraulic or bituminous binders.

In conclusion, the paper presents a range of materials made with household waste bottom ash and lists their uses. These are:

- Processed and calibrated bottom ash aggregate, used as fill or as a pavement sub-base,
- Bottom ash treated with hydraulic binder for use in sub-base and lower base courses,
- Bottom ash treated with foamed bitumen for use in base courses, and finally,
- Bottom ash based concretes with specific applications in drainage trench filling and pavement widening.

These products are the result of a vigorous research effort and they illustrate outlets for a technically and economically viable waste recovery sector.

1. Introduction

In road construction techniques, bottom ash was traditionally used for site access roads. Today, its area of use has developed considerably thanks to minimum preparation, iron removal and screening the raw bottom ash. The May 1994 Circular issued by the French Ministry for the Environment stipulated that bottom ash with a low leachable fraction can be used, under certain conditions, as backfill, sub-base and lower base courses. In addition to the environmental aspect, addressed in the above-mentioned Circular, that restricts its use, the strict application of standard geotechnical criteria further substantially limits its area of use. Thus, it is very often necessary to improve the quality of household waste bottom ash. This improvement can be viewed from two angles: environmental and geotechnical. In the first case, the aim is to reduce the impact on the natural environment, and in the second to increase its mechanical performance. The improvement in the quality of household waste bottom ash leads to a broader potential area of use, from which it follows (a) improved recycling of the material using it in road base courses for a broader range of traffic classes, and (b) less consumption of noble natural aggregate. Thus, the expected advantages are twofold: a reduction in the direct and indirect impact on the environment, and a reduction in the overall cost of managing household waste bottom ash by increasing the added value of the resultant products produced.

2. Characteristics of bottom ash

2.1. Geotechnical characteristics

By way of example, a study of 8 household waste bottom ash production sites, of which one outside France, has enabled bottom ash characteristics at the preparation unit outlet to be defined. Based on the main geotechnical parameters used to define the material, it has been demonstrated that the average qualities of household waste bottom ash are lower than those of traditional materials.

Table 1 gives the average, maximum and minimum figures for the samples from these 8 sites.

Parameter	S.g.	L.A.	M.D.E.	Sand equivalent	V.B.S.
Average	2.35	41	34	44	0.03
Minimum	2.25	36	26	38	0.02
Maximum	2.46	49	39	49	0.05

Table 1 - Geotechnical characteristics of bottom ash from 8 sites.

The real s.g. of household waste bottom ash is low compared with natural aggregate making it a rather light material. In terms of hardness, the Los Angeles (L.A.) test and Micro Deval in the presence of water (M.D.E.) test rank it at the upper level of category E[1] of the Aggregate Standard (XP P 18 540 [1]). Despite a relatively low Sand Equivalent, the very low Methylene Blue Value of a Soil (VBS) is characteristic of materials devoid of clay. The grain size curves (Figure 1) show that it is a well-graduated 0/20 aggregate whose envelope is contained within the Untreated Aggregate 0/20 envelope, type A, of the Standard NF P 98-129 [2].

[1] Aggregate is classified by decreasing order of quality from A to F. Class E is characterised by: (L.A. < 45 ; M.D.E. < 45 ; L.A. + M.D.E. < 80).

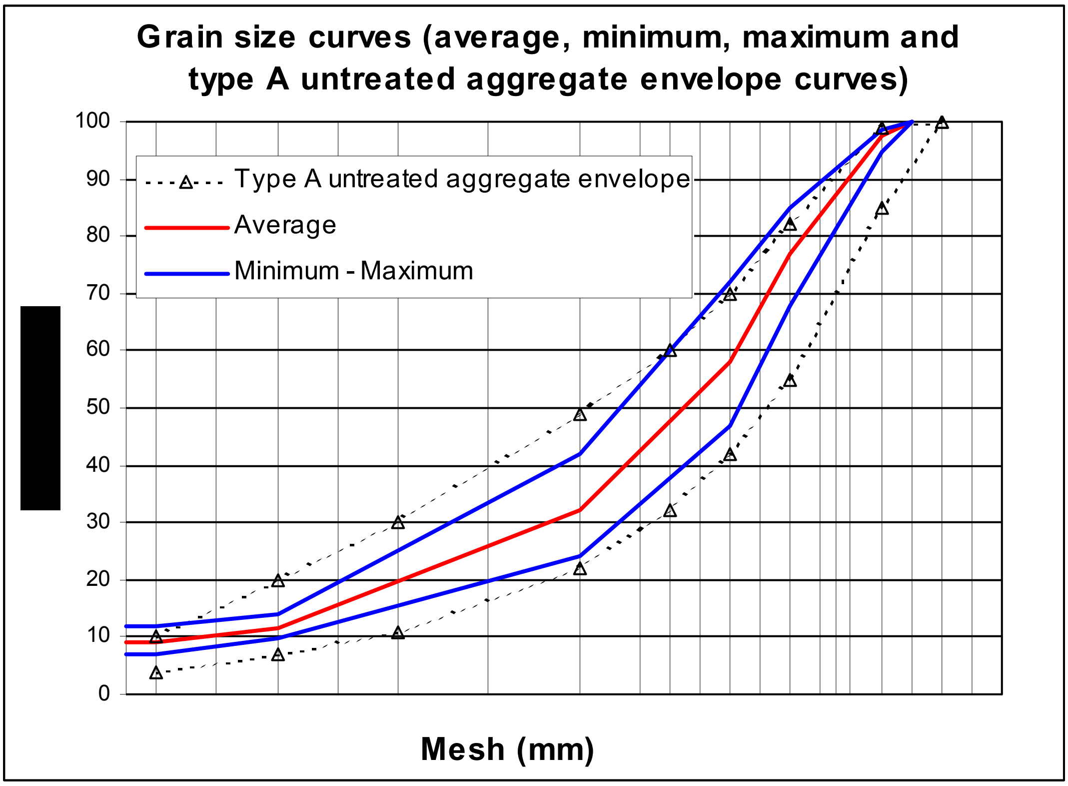

Fig. 1 – Bottom ash grain size curves

Its Modified Proctor Optimum (Standard NF P 94 093 [3]), 12% < water content < 16% and 1.75 ≤ apparent dry density < 1.90, makes it a very particular material. Finally, the Bearing Capacity (BC), 30 < BC > 60, characterises a relatively stable material that is still quite sensitive to an excess of water when installed. Its potential use, defined by the *Guide Technique pour la Réalisation des remblais et des couches de forme* [4] and by the *Guide Technique pour l'utilisation des matériaux régionaux d'Ile-de-France (MIOM)* [5], shows that it is only envisaged in its untreated form, and that its area of use is restricted to the base courses of roads with very light traffic densities.

2.2. Environmental characteristics

Recycling bottom ash in road techniques is dependent on its not polluting the natural environment. At present, the environmental criteria to be respected are defined in the May 1994 Circular issued by the French Ministry for the Environment which provides a bottom ash classification grid as a function of the pollutant content in the bottom ash or released during a leaching test (Table 2).

	Units	"V" bottom ash	"M" bottom ash	"S" bottom ash
Unburned residue(1)	%	< 5	< 5	> 6
Soluble fraction(2)	%	< 5	< 10	> 10
Leachable Hg(2)	mg/kg	< 0.2	< 0.4	> 0.4
Leachable Pb(2)	mg/kg	< 10	< 50	> 50
Leachable Cd(2)	mg/kg	< 1	< 2	> 2
Leachable As(2)	mg/kg	< 2	< 4	> 4
Leachable Cr^{6+}(2)	mg/kg	< 1.5	< 3	> 3
Leachable SO^{2-}_4(2)	mg/kg	< 10 000	< 15 000	> 15 000
Leachable TOC(2)	mg/kg	< 1 500	< 2 000	> 2 000

Table 2 - Categories of bottom ash as a function of its pollution potential pursuant to the May 1994 Circular issued by the French Ministry for the Environment: (1) quantified by calcination of solids, (2) quantified after leaching, as defined in Standard NF/X31-210 [6], from the solution obtained and expressed by weight compared with the initial solid weight.; V, Recyclable; M, Maturable; S, Stockable.

Compliant with the Circular, category S bottom ash is non-recyclable and must be disposed of in a Category II landfill. At the opposite extreme, Category V bottom ash can be used as is. The intermediate category M can be used subject to specific prior treatment to bring it into line with the characteristics of category V. This treatment may be a simple maturation process, but may also entail chemical stabilisation using one of several processes.

3. Avenues for improvement

3.1. On the geotechnical level

Improvement of the geotechnical characteristics of a material such as bottom ash, with low hardness and attrition resistance characteristics, can be achieved in three ways:

- Treatment with a binder, generally hydraulic or hydrocarbon-based. The resultant significant increase in the material's cohesion means that the insufficiency of some geotechnical characteristics can be partially or totally offset;
- Granular correction by the addition of harder aggregate;
- Seeking synergy with another material or another waste product. For example, the addition of household waste bottom ash to "Sea aggregate" without fines will overcome the insufficiency of fines, and the sea aggregate will compensate for the insufficient hardness of the bottom ash. Similarly, the addition of fine sand treated with hydraulic binders will provide granular correction and provide the resultant mixture with immediate sufficient stability for easy application and allow for construction site traffic loads without any deterioration to the material.

3.2. On the environmental level

Two methods are generally considered for reducing the pollution potential of bottom ash: one physical and the other chemical. The physical method consists in solidifying the ash by adding a binder. This method traps, by coating or encapsulation, the pollutants in solid materials with low permeability. The chemical method seeks to stabilise the pollutants by immobilising them with strong chemical bonds in non-hydrolysable complexes in an alkaline or acidic environment.

a. Treatment with a hydraulic binder

This type of treatment takes advantage of the effects of chemical solidification and stabilisation by trapping the pollutants in the various mineral phases formed (silicates, hydrates, carbonates, etc.). The pollutants can be trapped by several different processes:

- Precipitation of mineral phases incorporating the pollutants,
- Adsorption on the new surfaces created,
- Localised ion exchange in privileged sites.

In practice, treatment with a hydraulic binder will cut the concentration of the main pollutants in leachates by roughly 50%. An example is given in Table 3.

b. Bitumen treatment

Bitumen only has a physical effect resulting in the material's coating and densification thereby limiting its permeability and so the migration of pollutants. Although relatively less effective than treatment with hydraulic binders, this technique also reduces the concentration of pollutants in the leachates (Table 3).

		Treatment with hydraulic binders			Treatment with foamed bitumen		
Analyses	**Unit**	**Ash alone**	**Treated ash**	***Reduc-tion***	**Ash alone**	**Treated ash**	***Reduc-tion***
Soluble Fr.	**%**	2.23	0.56	*0.25*	2.29	1.24	*0.55*
TOC	**mg/kg**	200	117	*0.59*	482	272	*0.56*
Sulphates	**mg/kg**	11810	1410	*0.12*	2077	1205	*0.58*
Cr (total)	**mg/kg**	0.15	0.15	-	0.27	0.15	*0.55*
Mercury	**mg/kg**	0.03	0.03	-	0.03	0.03	-
Lead	**mg/kg**	0.03	0.03	-	0.03	0.03	-
Cadmium	**mg/kg**	0.06	0.03	-	0.06	0.03	-
Arsenic	**mg/kg**	0.03	0.03	-	0.03	0.03	-

Table 3 – Effect of treatment on pollution leaching.

4. Bottom ash problems

The use of bottom ash in pavement base courses, without taking any particular precautions, may lead to problems specific to the treatment method.

4.1. The findings

With untreated bottom ash used as untreated aggregate under a thin bituminous course, "mass" swellings of several % or isolated swellings have been found. The latter have a diameter of several centimetres to several tens of centimetres, depending on the thickness of the bituminous course, and can be up to 2 to 3 cm high.

For bottom ash treated with hydraulic binders, the problems are different. They are of three types:

- Resistance to setting or very low mechanical strength,
- Cracking in mixes that have set well,
- Loss of mechanical strength after several months.

For bottom ash treated with bitumen covered with a bituminous course, only surface swelling has been noted (Fig. 2). It is very similar to that found with untreated bottom ash.

Fig. 2 – Surface swelling

4.2. Causes

a. Swelling and cracking

Various investigations on isolated swellings and crack samples have revealed that the cause can be attributed to the presence of aluminium particles roughly a centimetre in size. These particles, through the corrosion of the aluminium in a favourable electro-chemical environment, are transformed into highly expansive hydroxides (Fig. 3).

Source of swelling ☞ aluminium

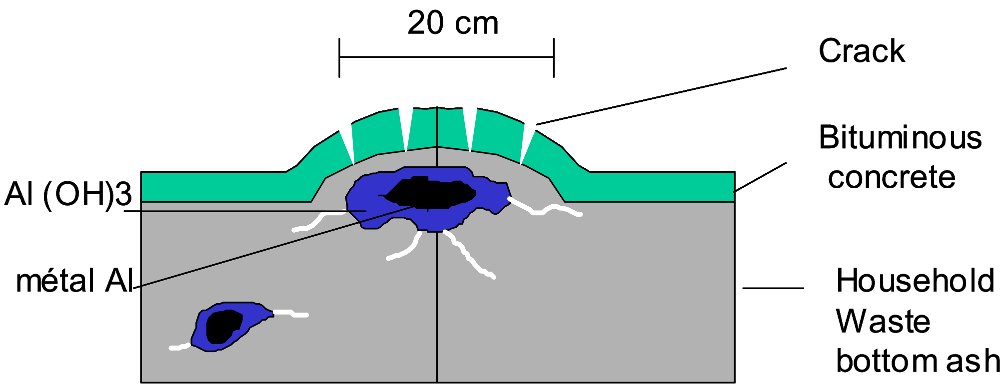

Fig. 3 – Diagram showing the formation of swelling

b. Non-setting phenomena

The interaction between the hydraulic binder and the components in the bottom ash is highly complex and the causes are no doubt many. Among these, the effective maturation of the bottom ash would seem important, as can be seen from Figure 4. The graph shows the effect of bottom ash maturation time before treatment with cement on the tensile strength after 14 days conservation in test tubes.

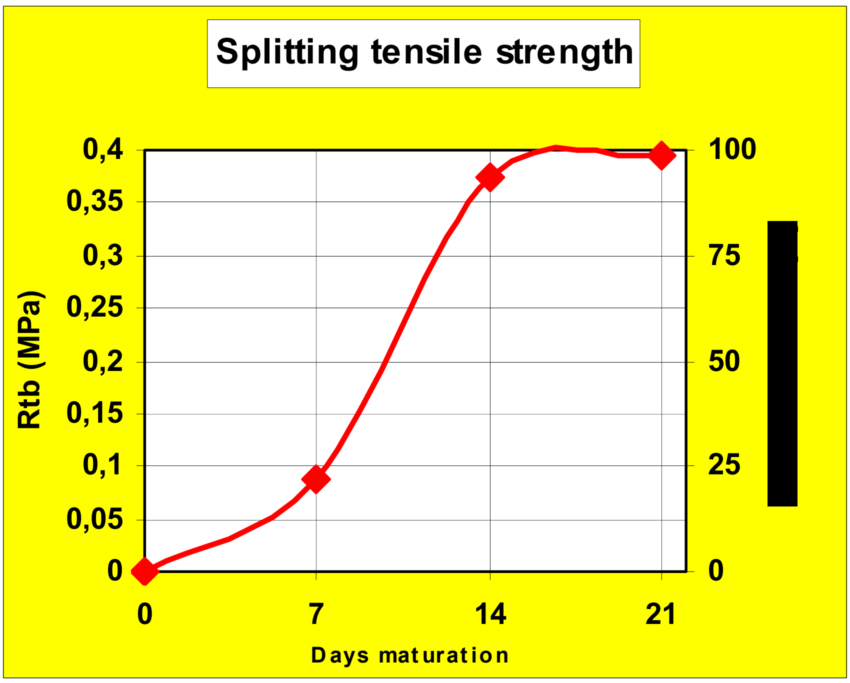

Fig. 4 – Effect of maturation (here accelerated) on the setting of bottom ash treated with hydraulic binders.

4.3. The solutions

a. Swelling

The first solution involves extracting the metal aluminium particles from the bottom ash using eddy current machines. This operation can be restricted to the larger fraction, 6/D for example, which contains the particles responsible for the swelling. The second involves making sure the bottom ash in the pavement is covered with a course of other material at least 15 cm thick. This thickness is generally sufficient to avoid the appearance of surface swelling.

b. Cracks and loss of strength of material treated with hydraulic binders

The solution involves separating out the aluminium as indicated above for swelling.

c. Non-setting phenomena

To limit the risk of the material not setting, ensure correct maturation and choose the appropriate binder.

5. Improvement techniques

5.1. Production of untreated aggregate

This involves a more elaborate preparation than that referred to in the May 1994 Circular. It involves crushing, screening, two-stage iron removal, and separation of non-ferrous metals and the unburned light fractions. The result is an untreated aggregate, well calibrated at 0/20 or 0/31.5, of class A under French Standard NF P 98-129, with excellent dimensional stability.

5.2. Treatment with hydraulic binders

There are two techniques: the material treated with hydraulic binders and compacted technique and the cement concrete technique.

a. The material treated with hydraulic binders and compacted technique

The main binders used are either Portland cements, or special Road Binders, or even specific binders.
The binder content, generally between 5% and 8%, depends on the nature of the binder, of the bottom ash itself, and the desired class of mechanical performance.
By way of example, the mechanical characteristics obtained with various binders and dosages are given in Table 4, and compared with those for treated aggregate or sand.

PARAMETERS	Average figures		
	ATHB	BATHB	STHB
Tensile strength (MPa)	1.03	0.57	0.69
Modulus of elasticity (MPa)	22 500	7 100	10 500
Strain at failure	$46\ 10^{-6}$	$85\ 10^{-6}$	$66\ 10^{-6}$

Table 4: Average mechanical characteristics at 28 days (cement) or 60 days (Special Road Binder). ATHB (aggregate treated with hydraulic binders); BATHB (Bottom ash treated with hydraulic binders); STHB (Sand treated with hydraulic binders).

The strength and, above all, the stiffness of BATHB is markedly less than that of treated sand (STHB), as can be seen from the diagram in Figure 5 which gives all the results for the three families.

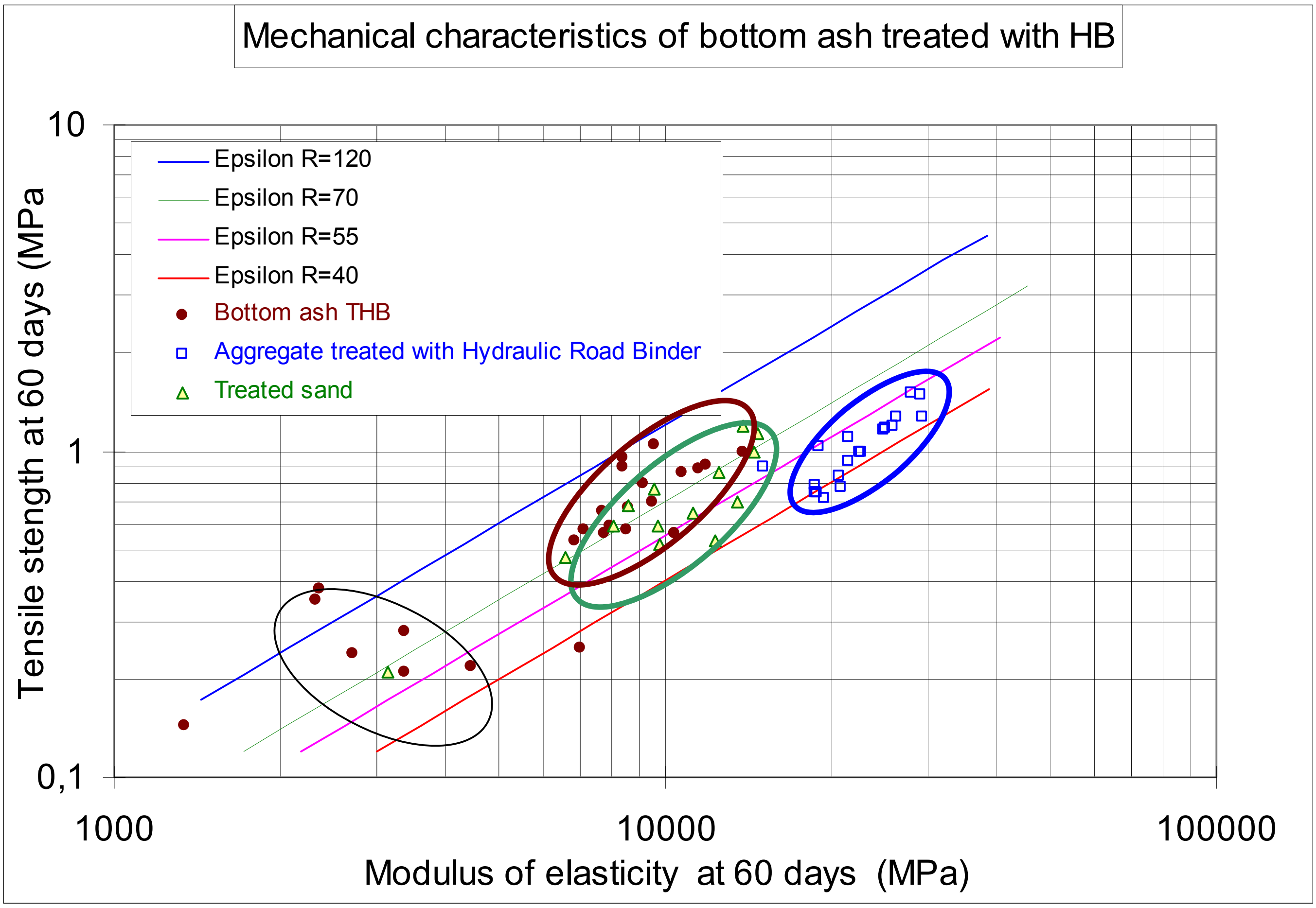

Fig. 5 - Mechanical characteristics of bottom ash THB compared with aggregate and sand THB

The bottom ash treated with hydraulic binders is thus classified in categories S2 and S3 of the classification of STHB (Standard NF P 98 113 [7]) as a function of the binder content in the mix.

b. Bottom ash concrete

The cement concrete technique can be used to produce products for roads:
- Self-levelling excavatable concrete (so with low strength) for drainage trench filling in compliance with the specifications of the *Centre d'Etudes sur les Réseaux, les Transports, l'Urbanisme et les constructions publiques* (Research Centre for Networks, Transport, Urban Development and Public Buildings);
- Self-levelling concrete with higher strength for sub-base or lower-base courses for applications where material compacting is difficult, low bearing soils or the base of narrow forms where only small compactors can be used.

5.3. Bitumen treatment

Hot and cold mix techniques are applicable to bottom ash. In France, there is, however, a preference for cold techniques.

a. Hot mixes

Formulation tests for bitumen aggregate have revealed the difficulty of arriving at formulae for bottom ash alone. The water resistance of the resultant mix is very mediocre (r/R = 0.15 (see Table), whereas the specifications stipulate > 0.6). This requirement means that only mixed formulae combining bottom ash and natural aggregate are used. Further, the need to heat the aggregate, generally with a direct flame, can be a source of additional problems.

b. Cold mixes

There are two treatment techniques: the first with an emulsion and the second with foamed bitumen. With these two techniques, unlike the hot technique, it is possible to comply with the performance specifications of the corresponding standard. Table 5 compares the three techniques in terms of the results of Duriez tests[2] (NF P 98 251-1 [8][9])

MATERIAL	BOTTOM ASH			NATURAL AGGREGATE		
TYPE	Aggregate Bitumen	Aggregate-Emulsion	Aggregate -Foam	Aggregate-Bitumen	Aggregate-Emulsion	Aggregate-Foam
Residual bitumen (ppc)	4.20	4.02	3.31	4.20	3.50	3.57
Richness modulus K[3]	2.52	2.42	1.80	2.52	2.12	2.13
Compressive strength (MPa)						
- Rc air	2.6	3.6	4.05	5.7	5.1	4.1
- rc water	0.4	2.3	2.26	4.0	3.2	2.63
Water resistance (rc/Rc) (see text)	0.15	0.64	0.56	0.70	0.63	0.64

Table. 5: Mechanical performance of bottom ash compared with natural aggregate according to three bitumen treatment techniques

[2] Duriez test: the test involves crushing cylindrical samples after 8 days storage, in air and in water. The ratio between the compressive strength rc (storage in water) and Rc (conservation in air) reflects the material's sensitivity.
[3] K: figure proportional to the standard thickness the film of binder coating the aggregate - (NF P 98 149 [10]).

6. Example of a range of products developed by one company

Using the example of a contractor, through expertise developed out of concerted research on household waste bottom ash, a range of products has been developed, which covers as large an area of use as possible (Table 6). Before treatment, non-ferrous metal is extracted from the bottom ash, and it is applied in compliance with the solutions identified.

Products	Treatment	Area of use	
	type of material	Functions	Traffic
SCORGRAVE	No binder Untreated aggregate	• Backfill • Sub-base • Lower base course	All traffic All traffic Light traffic
SCORCIM	Hydraulic binders Bottom ash treated with hydraulic binder	• High-performance sub-base resulting in PF3 or PF4 platforms • Mixed-structure lower base course.	All traffic All traffic
SCORSABLE	Fine sand corrected with bottom ash + HB Bottom ash treated with hydraulic binder	• Lower base course	All traffic
SCORMOUSSE	Foamed bitumen Bituminous mat.	• Lower base course • Sub-base	All traffic Average and low
SCORCAN	Hydraulic binders Cement concrete	• Excavatable for drainage trench filling	All traffic
SCORCAN PR	Hydraulic binders Cement concrete	• High strength for road widening edge beams	All traffic

Table 6 – Area of use of the SCORMAT range

7. Conclusions

Several decades ago, "intreated bottom ash " was being used for construction site access roads. Since then, considerable progress has been made in the quality of household waste bottom ash. The May 1994 Circular was a major turning point, as it defined the minimum conditions for preparation and an associated area of use for light traffic.

The past few years' research is beginning to pay off. It has focussed on:

- The preparation of household waste bottom ash,
- The development of new products with improved geotechnical and environmental qualities, and
- A better understanding of the real impact on the natural environment of structures using household waste bottom ash,

There are an increasing number of outlets, as the area of use no longer precludes the wearing course or base courses for heavy traffic.

References

[1] XP P 18-540 <>Granulats Définitions, conformité, spécifications

[2] P 98-129 <>Graves non traitées Définition - Composition - Classification

[3] P 94-093 <>Sols : Reconnaissance et essais Détermination des références de compactage d 'un matériau Essai Proctor normal - Essai Proctor modifié

[4] Guide Technique pour la Réalisation des remblais et des couches de forme septembre 1992 (SETRA-LCPC)

[5] Guide technique pour l'utilisation des matériaux régionaux d'Ile-de-France. Les mâchefers d'incinération d'ordures ménagères. Novembre 1998.

[6] XP X 31-210 <>Déchets Essai de lixiviation

[7] P 98-113 <>Assises de chaussées sables traités aux liants hydrauliques & pouzzolaniques

[8] P 98-251-1 <>Essais statiques sur mélanges hydrocarbonés PARTIE 1 : ESSAI DURIEZ SUR MELANGES HYDROCARBONES A CHAUD

[9] P 98-251-4 P 98-251-4 <>Essais statiques sur mélanges hydrocarbonés PARTIE 4 : ESSAIS DURIEZ SUR MELANGES HYDROCARBONES A FROID A L EMULSION DE BITUME

[10] P 98-149 <>Enrobés hydrocarbonés Terminologie Composants & composition des mélanges Mise en oeuvre produits Techniques & procédés