

# Mechanical properties of MSWI bottom ash in Denmark

## Les propriétés mécaniques du mâchefer issue des Usines d'Incinération d'Origines Ménagères au Danemark

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### ABSTRACT

In Denmark, traditionally Municipal Solid Waste Incineration (MSWI) bottom ash has been used as structural fill and especially as capillary layer beneath floors. The latter practice started in the 1960ties in urban family houses and has continued for more than 20 years. Gradually, the tradition using bottom ash beneath floors has been adopted for large storehouses as well.

When dry bottom ash is subjected to increasing moisture content it often expands. This expansion of the bottom ash occurs with increasing moisture content and may result in heave of the floor and even squeezing out of the footing. In many cases the floor has to be removed and the bottom ash replaced by sand. This is a serious problem for many house owners especially when they want to sell the house and the word bottom ash appears in the design drawings.

A series of laboratory tests have been performed examining the expansion of bottom ash with different moisture content history, e.g. the bottom ash has been moistened for 0, 3 and 6 month and the expansions have been followed to see if the expansion stops after a certain time interval. According to the tests the expansion effect is reduced considerably when the moisture content has been high for a few months, but there is still a tendency to a small residual expansion, probably due to a relatively high content of iron.

### RÉSUMÉ

Au Danemark, traditionnellement, certains résidus solides de la combustion issues des Usines d'Incinération d'Origines Ménagères (UIOM), ou mâchefer, sont utilisés comme remblai structurel, notamment comme barrière capillaire sous le plancher. Cette pratique relativement récente a commencé dans les années 60 dans les maisons en milieu urbain, et a duré pendant plus de 20 ans. Dans ce même temps, cette utilisation du mâchefer comme remblai sous le plancher a de plus en plus été adoptée pour de plus grands bâtiments.

Quand le mâchefer, qui est une matière sèche, est soumis à l'humidité, celui-ci se dilate. La dilatation de ces résidus solides de combustion a lieu quand la teneur en humidité augmente, et peut résulter par un soulèvement du plancher, voire une pression sur les murs porteurs. Dans de nombreux cas, le plancher a dû être retiré, et le mâchefer remplacé par du sable. C'est un problème important pour les propriétaires, surtout quand ceux-ci souhaitent vendre leur maison et que ce type de remblai est mentionné dans la conception de la maison.

Des séries de tests ont été menées en laboratoire sur la dilatation du mâchefer avec différents niveaux d'humidité dans le temps, entre autres sur 0, 3 et 6 mois. Puis ces dilatations ont été suivies pour voir si ce phénomène s'est estompé après un certain temps. D'après ces tests, l'effet de dilatation se réduit considérablement après que la teneur élevée en humidité est maintenue pendant quelques mois, mais il y aura toujours une tendance à une légère dilatation résiduelle, probablement due au contenu élevé de fer.

Keywords: Bottom ash, expansion, moisture content history, municipal solid waste, capillary layer, hydration, carbonisation, iron

## 1 THE HISTORY

In Denmark and probably most of Europe the amount of municipal solid waste has grown enormously from 1950 to today. Most of the solid waste is being incinerated in big plants. It results in an enormous amount of bottom ash, at least 250,000 tons per year in 2010 in the eastern part of Denmark.

At the beginning of the 60 years period a major part of the bottom ash was stockpiled and covered with topsoil - for eventually later use - forming landscapes or it was used as material in local paths and roads. Part of the bottom ash was already in the 1960ties used as structural fill, especially as capillary layer beneath floors in family houses. The praxis continued for more than 20 years and the tradition using bottom ash beneath floors has during the past 20 years been adopted for constructing large storehouses as well.

However, due to expansion of the bottom ash when exposed to increasing moisture content problems with heave of floors and movements of the base have occurred. In many cases floors had to be removed and the bottom ash fill layer replaced by sand fill. This has been a serious problem for many house owners and the problem still exists especially in the situation when the owners want to sell the house and bottom ash fill is revealed from the original design drawings.

## 2 THE BOTTOM ASH

A typical Danish bottom ash is a well graded material with a grain size distribution curve as indicated in fig. 1.

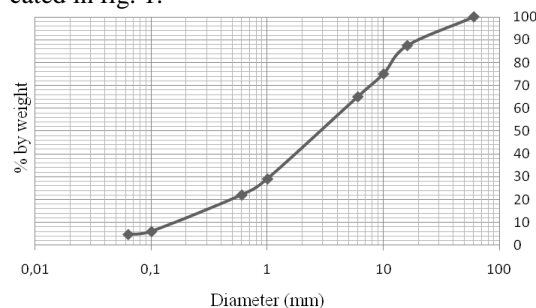


Fig. 1. Typical grain size distribution curve for bottom ash

The curve lies within the limits for gravel used as load bearing fill material.

The grains are irregular in shape with a grain density in the interval of 2.57 to 2.82 Mg/m<sup>3</sup> which are relatively close to the density for quarts grain 2.65 Mg/m<sup>3</sup>.

The loss on ignition at 440°C is in the interval of 1.7 to 2.4 %.

The maximum dry density in a standard proctor test is relatively low and lies at the level of 1.8 Mg/m<sup>3</sup> together with a high optimum water content of approx. 15 %.

Los Angeles Abrasion test results around 45 % indicate a relatively low strength of the grains compared to ordinary sand and gravel grains.

### 2.1 Strength and deformation parameters

Based on triaxial tests in the laboratory an estimation of the strength and deformation parameters for a density index of 0.3 to 0.6 the triaxial friction angel is measured in the interval of  $\phi = 38^\circ$  to  $41^\circ$  with a minor and often neglected effective cohesion.

The constrained deformation modulus measured by oedometer tests may be 14 MN/m<sup>2</sup> and 20 MP MN/m<sup>2</sup> for density index of 0.3 and 0.6 respectively for first time loading up to a load intensity of 200 kN/m<sup>2</sup>. For higher load intensities bottom ash fill will behave as normal consolidated soil with a compression index of approx.  $Q = 0.1$  % (in a  $\epsilon, \log \sigma$  diagram).

### 2.2 Hydraulic parameters

The draining properties and the capillarity are primarily based on the content of fine material.

If the capillary rise is defined as  $h_c = (30 \text{ to } 60) / d_{10}$  mm and the permeability as  $k \approx 0.01 \times d_{10}^2$  m/s, where  $d_{10}$  = diameter of grains at 10% by weight, we calculate the values in the table below.

The draining properties of bottom ash expressed by the coefficient of permeability are not as good as for sand and gravel. To use bottom ash as capillary layer beneath a floor it typically requires a layer thickness twice the capillary rise for the material, e. g. the required layer thickness should be 240 to 1000 mm. This indicates that

unless the bottom ash layer is very thick it is not a very good capillary layer.

Grain diameter	Capillary rise	Coefficient of permeability
$d_{10}$ (mm)	$h_c$ (mm)	$k \cdot 10^{-4}$ (m/s)
0.12 - 0.25	120 - 500	1.4 - 10.0

Table 1. Calculated hydraulic parameters for bottom ash

### 2.3 Expansion

It is known that bottom ash used as capillary layer below floors under special conditions may expand. It is often recognised as heave of the central part of the floor, because here only a very small pressure is needed to lift the floor. Heave up to 10 % of the thickness of the bottom ash layer is seen. Expansions occur mostly due to hydration and carbonisation of calcium, magnesium and/or iron oxides in moistened *fresh, dry* bottom ash. The water may come either from capillary water, from leaky pipes or because of lack of drainage around the building.

To get away from the unsuitable use of fresh, dry bottom ash the handling process has changed so bottom ash now is kept in an *open* stockpile for approx. half a year, where the bottom ash is exposed to weather (by rain and wind) and further sprayed with additionally water in dry periods. The aim of stockpiling the bottom ash is to get over the chemical expansion processes before use. To verify this theory GEO has started a series of tests as described below.

### 2.4 Compaction

Weather exposed bottom ash delivered from stockpile has relatively high water content, but because the optimum water content is even higher (approx. 15 %), it is sometimes necessary to add more water. Because of the irregular shape of the grains bottom ash fill requires high energy to be compacted, which on the other hand gives a risk of crushing some of the grains which again gives more fine material. It is essential to select a

way to compact the bottom ash fill without crushing it.

## 3 TEST SERIES

A series of tests have been performed examining the expansion of bottom ash subjected to different moisture content history, e.g. the fresh bottom ash has been moistened for 0, 3 and 6 month and the expansions have been followed to see if the expansion stops after a certain time interval. The purpose of the testing was to investigate if it is possible to produce a passive bottom ash by enforced longtime wetting prior to use for construction purposes.

Classification tests on these specific samples have given a grain density in the interval 2.57 to 2.67 Mg/m<sup>3</sup>, a water content before start between 12.7 and 15.3 %. They are both relatively low. The grain size distribution curves show  $d_{50} = 4.12$  to 5.61 mm and  $d_{10} = 0.25$  to 0.28 mm with a uniformity coefficient  $d_{60}/d_{10} = 21$  to 32. There is 1.1 to 3.1 % of very fine material passing the 0.063 mm sieve.

12 steel cylinders with a diameter and a height of 300 mm have been used (Photo No. 1 of five of the cylinders). The bottom is a stiff steel plate and covered inside with a geotextile. The vertical part of the form walls are inside covered with Teflon. The bottom ash has been installed at a density index = 0.6. The top cover steel plate itself is loose and gives a surcharge of 0.24 kN/m<sup>2</sup> which approximate 0.1 m concrete (floor).

The vertical deformations are measured by a dial gauge on the top of the cover with an accuracy of one hundred of a millimeter. At start they were set in zero position.

To a start all 12 samples were saturated through a small pipe stub at the bottom of the cylinder. Half of the bottom ash samples was kept saturated during the testing and the other half was drained again after 24 hours leaving but 5 to 10 mm above the bottom. The sample numbers are given in table 2.



Photo No. 1. Five of the 12 test cylinders each with dial gauge on top and a saturation pipe outside the cylinder

Sample (nos.)	Weather exposed period before test (month)	Water content during test period
1-2	0	Drained
3-4	0	Saturated
5-6	3	Drained
7-8	3	Saturated
9-10	6	Drained
11-12	6	Saturated

Table 2. Overview of sample numbers and testing conditions

The deformation measurements are shown in figure 2 and 3. The settlements at the beginning of testing are due to saturation of the bottom ash. The testing period has been more than 2 years (743 days).

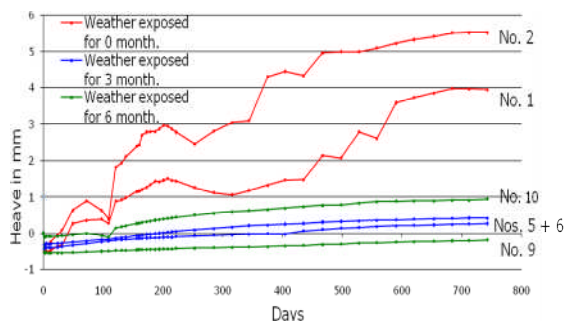


Figure 2. Heave development for drained bottom ash samples during test period

Weather exposed (month)	Heave in (mm)	Heave in (%)
0	4.0 to 5.5	1.3 to 1.8
3	0.3 to 0.4	0.1
6	-0.2 to 0.9	-0.1 to 0.3

Table 3. Total measured heave of drained bottom ash samples at the end of test period (743 days)

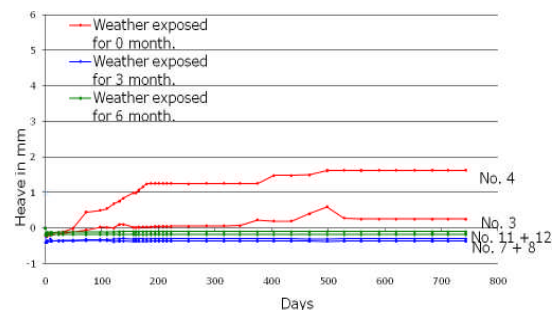


Figure 3. Heave development for saturated bottom ash samples during test period

It appears from the drained samples in fig. 2 and table 3 that the expansion effect is reduced considerably (with a factor of 10) when the moisture content has been high for a few months, but there is still a tendency to a small expansion up to some 0.3 %, probably due to the relatively high content of iron.

Weather exposed (month)	Heave in (mm)	Heave in (%)
0	0.3 to 1.6	0.1 to 0.5
3	-0.3 to -0.4	-0.1
6	-0.2 to -0.1	-0.1

Table 4. Total measured heave of saturated bottom ash samples at the end of test period (743 days)

The heave of the saturated samples in fig. 3 and table 4 is very small and almost negligible. Only the fresh bottom ash gives a small heave, but it is still below 0.5 % of the sample height.

This small heave is probably due to lack of air (oxygen) and the heave may accelerate if the bottom ash is drained.

#### 4 GENERAL EXPERIENCE

Because of the contents of fine material bottom ash cannot be used as capillary layer unless it is installed in a very thick layer.

Bottom ash expands primarily due to hydration and carbonisation of calcium. This is the primary reason for the expansion and it develops relatively fast.

A secondary and relatively slow expansion is due to precipitation of rust.

It is GEO's experience that a water content of 20 to 25 % seems to initiate the chemical processes.

The expansion of fresh bottom ash below floors may result in heave of floors (up to 10 %) and of movements of the base as well.

Furthermore, salts may rise through the concrete floor and destroy the bindings in the concrete structure and be visible as sodium sulphate salts on the floor.

#### 5 CONCLUSIONS

The testing carried out demonstrates that it is possible to reduce the expansion from the hydration and carbonisation processes considerably by moistening the fresh bottom ash for a period of some months before using it as structural fill.

Due to the high content of metals in the bottom ash there will still remain a relatively small and slow expansion due to precipitation of rust.

Thus it may still be a problem to use weather exposed bottom ash below floors or generally in contact with concrete structures when no movements are accepted.