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Soil mechanical properties of bottom-ash from municipal solid waste incineration

Propriétés sol méchanique des cendres de l´incinération de déchets

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ABSTRACT: From research investigation on MSW bottom-ash it was found that the mechanical behavior changes depending on time, original compaction, availability of water, loading conditions etc. The change in mechanical behavior is due to chemical reactions generating minerals like calcite, gypsum, ettringite and CSH phases. A mathematical approach was found to calculate peak strength and strain softening of the material from triaxial test. Values from research experience are given.

RESUMÉ: Cendres de déchets se comporte différemment en fonction du temps, le tassement original, disponibilité de l'eau, les conditions de charge etc. La modification dans le comportement mécanique tient aux réactions chimiques qui causent la disposition des minéraux comme la calcite, le gypse, l´ettringit et des phases CSH. Une approche mathématique s'est avérée pour calculer la force maximale et pour tendre se ramollir du matériel. Des valeurs de l'expérience sont indiquées

1 INTRODUCTION

Series investigation on 8 bottom-ashes from municipal solid waste incineration (MSW bottom-ash) showed high time dependency of chemical/mineralogical as well as mechanical properties. One MSW bottom-ash was examined in detail. On the basis of soil mechanical classification tests three different mixtures ($D_{Pr} = 1,0$, $D_{Pr} = 0,97$ on the dry and on the wet side of optimum) were investigated regarding their strength development and their mineralogical change with time. Triaxial test, XRD-powder diffraction analysis and SEM were conducted at curing times of 1, 7, 28 days 6 and 12 months. Further a mathematical approach was developed to describe the stress-strain behavior.

2 MINERALOGICAL DEVELOPMEN OF MSW BOTTOM-ASH over one year

Unlike most soils MSW bottom-ashes are not chemically inert materials. Their chemical composition is similar to inorganic binding agents and the following reactions are to be expected as major cause of change in strength: hydration of calcium, carbonisation, formation of CSH phases, hydration of anhydrite to bassanite and gypsum, hydration of aluminum and formation of ettringite. These reactions are dependent on the availability of water, air, different elements and curing time. Table 1 gives a review of the expected chemical reactions, the timeframe the associated mechanical change.

Figure 1 shows the mineralogical change within one year from XRD powder diffraction analyses. The content of anhydrite [Anh(020)] decreases while the content of gypsum [Gy(001)] increases. After 7 days ettringite [Ett(100)] starts to form from gypsum, calcite [Cc(104)] and aluminum (not shown in

Table1. Hardening reactions of MSW bottom-ashes.

Chemical reaction	Timeframe of the reaction	Change in behavior
Calciumhydrate	a few hours depending on availability of water	high alkalinity
Calciumcarbonate (calcite)	after 2 weeks, stable after 3 months	hardening
Calciumsilikahydrate	weeks up to decades [Gallenkemper/Regener (1993)]	hardening
Aluminiumhydrate	small particles within the first weeks, larger particles within decades [Lahl (1992)]	gasformation hardening
Ironhydrate	5-10 years [Lichtensteiger (1996)]	hardening
Sulfuroxidation		volumeincrease
Hydartion of Calciumsulfate: Anhydrite → Bassanite→ Gypsum	Up to 2 weeks depending on the availability of water	hardening
Formation of complexe crystals → ettringite	After a few weeks up to years	hardening volume increase

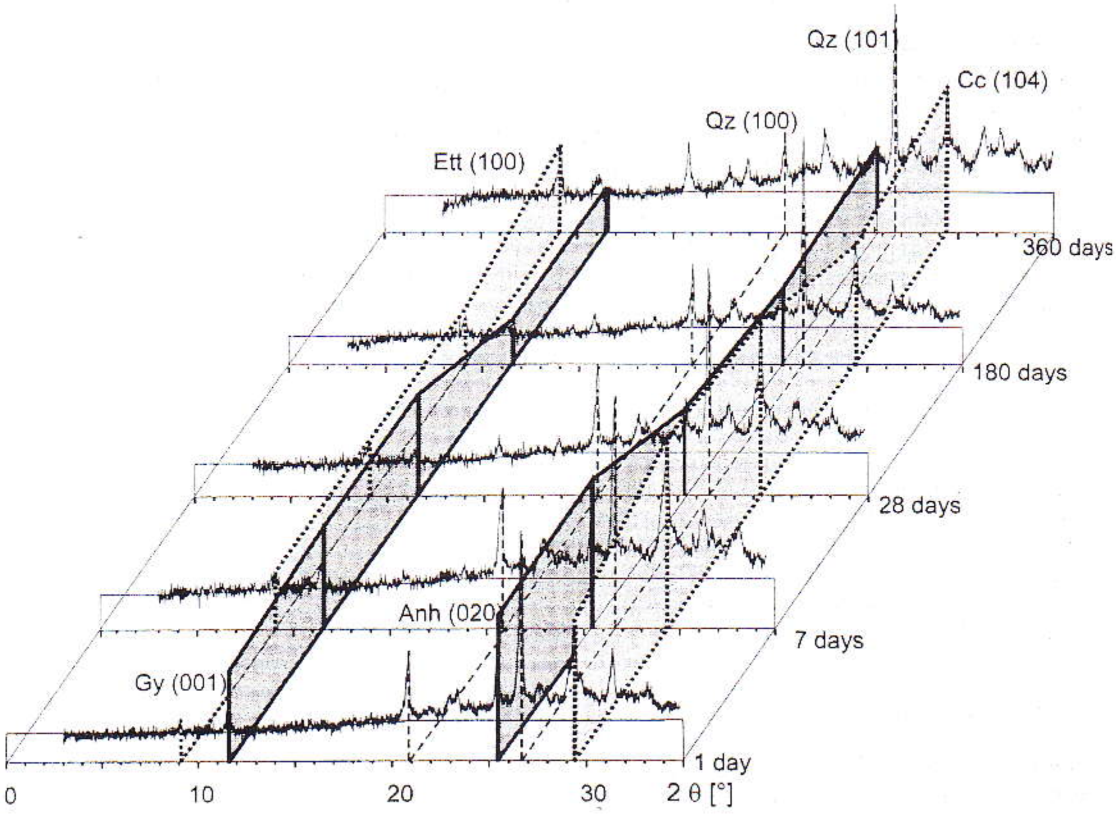

Figure 1. Change of mineralogical composition within one year

figure 1). Calcite is increasing over the period of one year. Gypsum and calcite contribute to hardening. Ettringite causes hardening of the material as long as enough pore volume is available if not, the volume increase of ettringite formation breaks up the matrix and causes a loss of structure, strength and initial stiffness (E_i). This was found by the $D_{Pr} = 1,0$ mixture which showed significant gain of stiffness over 28 days and a significant loss subsequently. The mixtures with $D_{Pr} = 0,97$

showed increasing E_i values over one year, where $D_{Pr} = 0{,}97$ at the dry side of optimum developed higher E_i values as at the wet side of optimum. Furthermore strength gain is due to the formation of CSH phases partly which were shown by scanning electron microscopy (SEM), see figure 2. Figure 3 shows ettringite formation on a portlandite crystal.

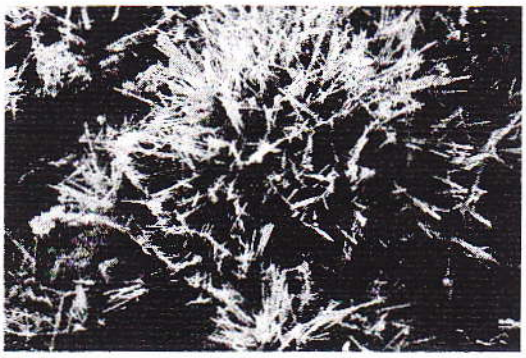
Figure 2. CSH at 180 days, BB = 105µm


Figure3. ettringite/portlandite at 180days BB = 21 µm

3 STRESS-STRAIN BEHAVIOR OF MSW BOTTOM-ASH

Before the mineralogical investigations triaxial tests were performed at the specimens. At 1 day a hyperbolic stress-strain relation ship was found. After longer curing periods strain hardening up to peak strength and strain softening was observed subsequently. Based on the hyperbolic stress-strain formulation (Kondner, Zelasko 1963) and (Duncan, Chang 1970) a mathematical formulation could be found to describe peak development and strain softening with increasing axial strain. Eq. (1) shows the formulation with only three curve parameters. In eq.(1) a can be assigned to the mechanical property of the initial stiffness (reciprocal of E_i), the parameters $\hat{b}, \bar{c}$ have to be determined by curve fitting. Only in the particular case of $\bar{c} = 1$ the curve reduces to a hyperbola with an asymptote of $2\hat{b}$.

$$\left(\sigma_1 - \sigma_3\right) = \frac{\varepsilon_1}{a + \hat{b}\left(\varepsilon_1 + \varepsilon_1^{\bar{c}}\right)} \qquad (1)$$

$(\sigma_1 - \sigma_3)$ and ε_1 mean deviatoric stress and axial strain from the conventional triaxial description. Figure 4 and figure 5 show a comparison between values from triaxial testing, the formulation from eq. (1), the hyperbolic model and the analyses from (Duncan, Chang 1963). It can be seen that eq.(1) gives good fit for the curves and is also able to take account for strain softening.

On the basis of 60 triaxial tests it could be shown that initial stiffness E_i is dependent on the mixture parameters like water content w and optimum density D_{Pr} as well as on stress level, see eq. (2).

$$E_i = \frac{D_{Pr} \cdot \left[\xi + \zeta \cdot \left(\frac{\sigma_3}{\sigma_{at}}\right)^n\right]}{\left(\sqrt{\frac{\left|w - w_{Pr}\right|}{w_{Pr}}} + \sqrt[3]{\frac{w}{w_{Pr}}}\right)} \qquad (2)$$

Volume development is contracting at low strains and dilating at higher strains. Table 2 gives values of experience from the research project for a first estimation of stress strain behavior using an elastic-perfectly plastic material model with a Mohr-Coulomb yielding condition and flow rule. More details can be found in (Ott 2001).

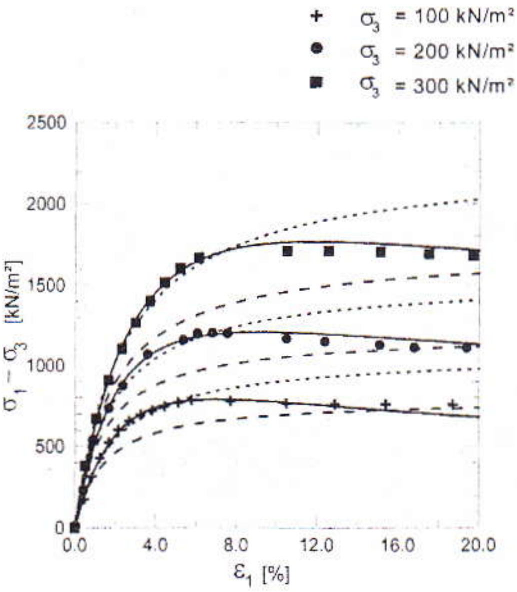

Figure 4. nonlinear stress-strain behavior at 1 day comparison of test values and mechanical models

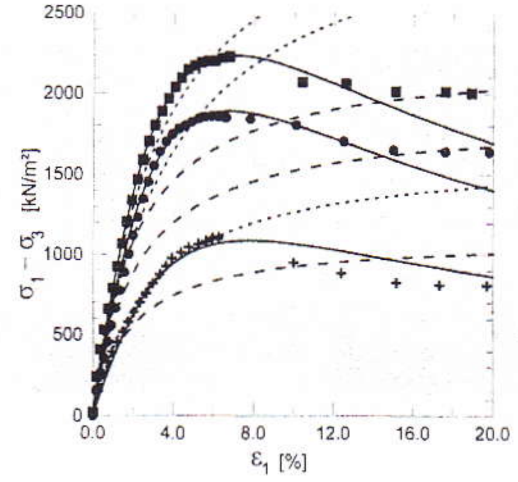

Figure 5. nonlinear stress-strain behavior at 360 days comparison of test values and mechanical models

Table 2. Collection of material parameter sets for MSW bottom-ash from 60 triaxial tests

model parameter	curing time [days]	values from experience		basic variables		
				material	Mixture	loading
E_i	1	53 - 83	[MN/m²]	w_{Pr}, χ, λ	w, D	α, σ_3
	360	40 - 137	[MN/m²]	w_{Pr}, D_{Pr}, ζ, ξ	w	σ_3, σ_{at}, ^{n}
φ	1	39,8 - 40,2	[°]	w_{Pr}, parameter$_{(t)}$	w	*
	360	47,2 - 49,4	[°]	w_{Pr}, parameter$_{(t)}$	w	*
c	1	62 - 80	[kN/m²]	parameter$_{(t)}$	w	*
	360	44 - 56	[kN/m²]	parameter$_{(t)}$	w	*
ψ	1	6,8 - 12,3	[°]	qualitative		
	360	3,2 - 9,9	[°]	qualitative		

*) needs further investigation

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