Base liner systems of dump sites with a longlasting contaminant protection by flatglass-elements

Systèmes d'étanchement de base de décharges à l'étanchéité à long terme par des plaques de verre

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ABSTRACT: The high chemical resistance of glass offers fascinating advantages for structures serving technical environmental protection. The development of the Integrated-Glass-Sandwich-Sealing at Darmstadt University of Technology enables the use of those advantages also for base liner systems of dump sites. In this new form of sealing system, flatglass-elements are integrated in mineral layers so that the longlasting impermeability of glass would be combined with the mechanical protection of the flatglass-elements. The feasibility of the Integrated-Glass-Sandwich-Sealing has been proved by extensive experimental investigations on its mechanical resistance.

RESUME: Le verre est un matériau qui, par sa haute résistance chimique, offre des avantages fascinants pour les ouvrages de protection de l'environnement. Avec le développement de l'étanchéité multicouche à plaques de verre intégrées, ces avantages pouvont être à l'avenir également utilisées pour les confinements de base de décharges. Dans ce nouveau procédé d'étanchéité, des plaques de verre sont intégrées en alternance avec couches d'argile compactée et combinent ainsi l'imperméabilité à long terme du verre et la protection mécanique des plaques de verre. L'adéquation du verre aux confinements a pu être montrée grâce à de nombreux essais de résistance et de faisabilité.

1 INTRODUCTION

Constructions and materials for sealing systems of dump sites in particular have to fulfil the requirements of impermeability and long-lasting resistance. The standard design sealing system combines mineral and synthetic layers. The specifications for dump sites (build in Germany) are fixed in the Technical Instructions, called TASo (1991) and TASi (1993). Alternative sealing-systems providing equal abilities are possible. The ideal construction material seems to be glass which shows the following advantages:

1. impermeability
2. corrosion resistance and durability on long-term basis
3. high bearing resistance
4. 100% recycled glass can be used

Using flatglass-elements in base sealing systems for dump sites is a new development and therefore the efficiency and feasibility of the system has to be proved. A basic research program considering the permeability, the load-deformation-behaviour, the shear-strength and the construction-method has been carried out.

2 THE SYSTEM PROPERTIES

The sealing-system contains flatglass-elements integrated in mineral sealing layers. The cross section and the layout of the flatglass-elements is shown in figure 1. The properties of the mineral layers and the dimensions of the flatglass-elements should be adapted to site specific requirements. The cross joints between the flatglass-elements are about 1 cm wide and can be sealed by natural and synthetic sealing materials (bentonite, bentonite cement, silicon etc.). The area of the joints is about 0,5% of the dump site ground area. Thus waterflow and contaminant transport can be reduced to a large degree.

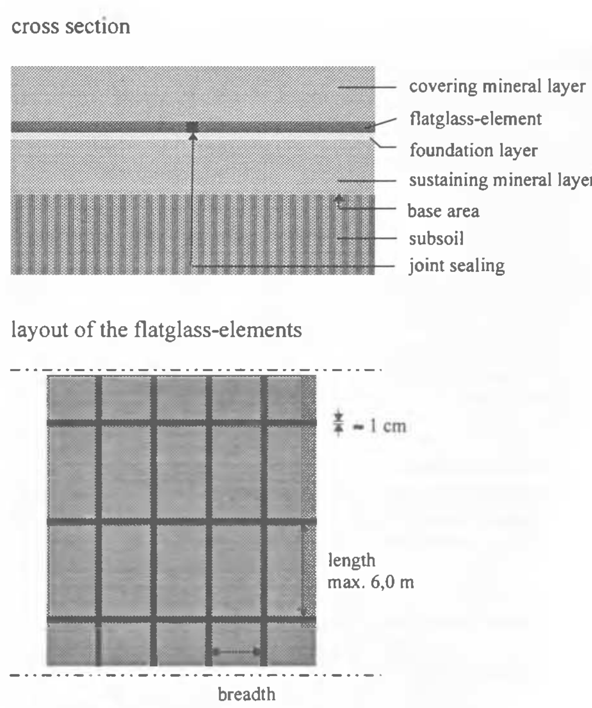

Figure 1. Integrated-Glass-Sandwich-Sealing

3 PROPERTIES OF THE FLATGLASS-ELEMENTS

Customary structural glass is used for the flatglass-elements. It consists of silica (71-75%), soda (13-15%) and lime (8-9%). Glass is an amorphous, homogenous, isotropic material. So its properties are independent of the direction. The load-deformation behaviour is linear-elastic. An extensive overwiew of the mechanical properties of glass is given by Petzold et al. (1990) and Wörner, Sedlacek (1991).

The strength of glass is determined by the surface conditions, especially macroscopical cracks. Stresses on the surface lead to load concentration at the crack tip. If the load concentration exceeds the molecular strength of glass, crack growth and breaking will arise. This process is influenced by water decreasing the bond energy of the atoms at the crack tip. Water also reacts with glass under stress and causes a time-dependent reduction of strength (Wiedehorn, 1967).

The design strength in case of long duration load and constant water contact stated in table 1 subsumes all these effects on the strength for the flatglass-elements of the Integrated-Glass-Sandwich-Sealing.

Glass, especially glass with a high rate of silica, is known for its chemical inertness and general resistance. The resistance of soda-lime-silica-glass is effected by the electrolyte pH (table 2). Scholze (1988) gives a summary of chemical reactions of glass.

The contact with water and acids leads to a lixiviation of alkali and alkaline earth. This effects an insoluble SiO_2-protective coat on the surface, which stops further corrosion. The resistance against alkaline solutions depends essentially on the temperature. Hot alkaline solutions attack the $[SiO_4]$-netting which leads to a dissolution of the glass. However this effect is unlikely because leachate of dump sites arises as concentrated or diluted aqueous solutions. As the rate of reaction in contact to aqueous solutions is negligible small, glass can be considered as chemical resistant (Scholze, 1988).

4 PERMEABILITY

Requirements to the contaminent protection by sealing systems of dump sites are not fixed by rates of admissible pollutions.

So the classification is done comparative to the standard design and given by three criteria (AK GDSA 1995):

1. stationary flow: q $[m^3/s]$
2. stationary contaminant transport: $\dot{m}$ $[g/(m^2 \cdot s)]$
3. induction time (duration until the first pollution arise): t_i [s]

The permeability of the Integrated-Glass-Sandwich-Sealing is very small compared to the standard design sealing systems

Table 1. Mechanical properties of glass

Property	Symbol	Unit	Value
density	ρ	g/cm^3	2,5
tensile strength	σ_z	N/mm^2	20 - 100
compressive strength	σ_d	N/mm^2	400 - 900
Young modules	Y	N/mm^2	70.000 - 74.000
Poisson's ratio	ν	-	0,22-0,25
thermal expansion coefficient	α_T	K^{-1}	$8 - 9 \cdot 10^{-6}$
design strength in case of long duration load and constant water contact	σ_{zul}	N/mm^2	6-10[1)]
design strength in case of short duration load (DIN 1249, T10)	σ_{zul}	N/mm^2	30

[1)] The design strength for floatglass in case of long duration load is not stated in the German design standards. The values given in table 1 represent the current design practice of structural glasing constructions (Sagmeister, 1993).

Table 2. Chemical resistance of soda-lime-silica-glass

Group of chemicals	resistance (concerning the mechanical properties)
acids (excluding hydrofluoric acid and phosphoric acid)	+
salts	+
water	+
alkaline solutions	0/-
hydrocarbons and hydrocarbonizations	+
alcohols	+
ester	+
ketone	+
oils and fats	+

+ resistant ; 0 limited resistant ; - not resistant

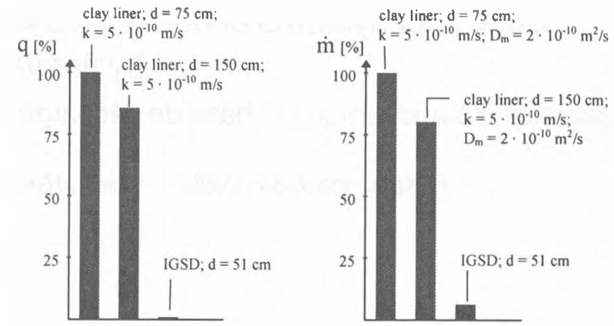

Figure 2. Comparative classification of stationary flow q and stationary chloride transportation $\dot{m}$

because the possible water flow and contaminant transport is reduced to the area of the joints. Thus the quantity is effected by

1. the dimensions of the flatglass-elements,
2. the properties of the sealing materials (permeability coefficient k; diffusion coefficient D_m) and
3. the capacity level h and the concentration c of the leachate.

Figure 2 shows the results of the stationary flow and stationary contaminant transport related to the quantities passing a 75 cm clay liner serving properties as requested in the design standard of the TASi (1993). The numerical calculations have been carried out for the following material properties and boundary conditions:

1. clay liners: $k = 5 \cdot 10^{-10}$ m/s, $D_m = 2 \cdot 10^{-10}$ m^2/s
2. joint sealing: $k_F = 1 \cdot 10^{-11}$ m/s, $D_m = 1 \cdot 10^{-10}$ m^2/s.
3. dimensions of the Integrated-Glass-Sealing-System:
   flatglass-elements: l = 6,0 m; b = 3,2 m; d = 10 mm;
   cross joints: b = 10mm;
   covering and sustaining mineral layer: d = 25 cm.
4. capacity level: h = 30 cm; chloride concentration at the top of the sealing: c_o = 40 g/l; chloride concentration at the bottom of the sealing: c_u = 0 g/l

The great advantages of the Integrated-Glass-Sealing-System is caused by the long-lasting impermeability of the glass. The longevity of synthetic sealing liners of the standard sealing systems is limited to 100 years. So on a long term base its effectivity is not given and the sealing is reduced to the mineral layer (AK GDSA, 1995).

5 MECHANICAL RESISTANCE

The durability of the flatglass-elements guarantees the long-lasting impermeability of the Integrated-Glass-Sandwich-Sealing. So the mechanical resistance of the flatglass-elements to all expected load cases has to be ensured.

The flatglass-elements are bedded in the surrounding sealing layers. Settlements at the dumpsite base are directly transmitted to the flatglass-elements. As the flatglass-elements are very thin, the load deformation behaviour is flexible in comparison to the ground, also in soft cohesive soil. Considering this, the decisive load cases for the flatglass-elements are:

1. Deformation of the flatglass-elements by settlements of the ground
2. Normal and shear stresses in the contact area of the flatglass-elements

5.1 BENDING TENSILE TESTS

The load deformation behaviour of the flatglass-elements and the sandwich-system has been proved by bending tensile tests. Figure 3 shows the trial installation with the test specimen. Flatglass-elements with a thickness of 8 mm are integrated in two mineral sealing layers, each 50 mm thick. The displacements of the test specimen are registered by inductive dial gauges, the extension of the flatglass-elements by resistance strain gauges.

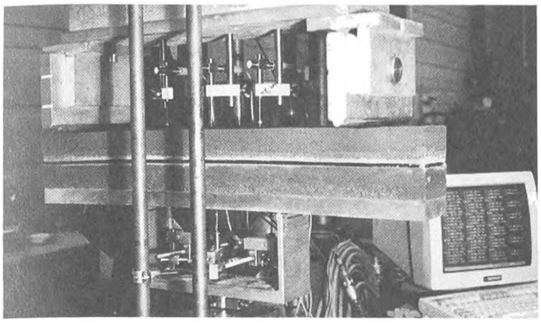

Figure 3. Trial installation for the bending tensile tests

The ultimate stresses arises at a bending radius of 6 to **8** m leading to a boundary stress of 36 to **48** N/mm². Considering the size of the design strength in case of long duration load and constant water contact is 6 N/mm² the minimum permitted bending radius is 60 m using flatglass-elements with a thickness of 10 mm. Compared to the required bending radius of 200 m of the German design standard the ductility of glass is sufficient.

5.2 PRESSURE TESTS

The dump site weight leads to contact pressure and normal stresses in the contact area of the flatglass-elements. The maximum load is about 0,9 MN/m² considering a dump site with a maximum hight of 60 m and a specific unit weight of the waste of 15 kN/m³. As the compressive strength of glass is very high (≥ 400 MN/m²) the amout of the transferable normal stresses is a question of the bearing conditions. They are effected by stress rises in the grain-glass-contact and the unevenness of the contact area. Tests in greater oedometers with Diameters of 300 mm and 1000 mm have been carried out to quantify those effects.

In contact to the course grains the glass breaking occurs by stress rise as shown in the tests with the gravel. In contact to the clay breaking occurs if the contact area is not uniformly plane. In case of an uniform bedding in sand and clay no breaking occured by loadings up to 5 MN/m². The grain size distributions of the test soils are shown in figure 5.

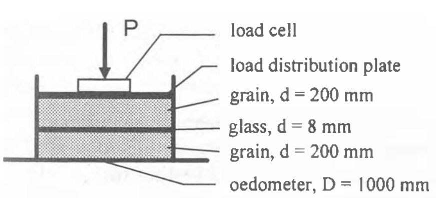

Figure 4. Trial installation (D = 1000 mm) for the pressure tests

Table 3. Compressive strength in the contact area glass-grain

contact grain	reached compressive strength [MN/m²]
gravel (GE)	0,12 - 2,4
sand (SE)	1,7 - 5,0
clay (TL)	1,7 - 5,0

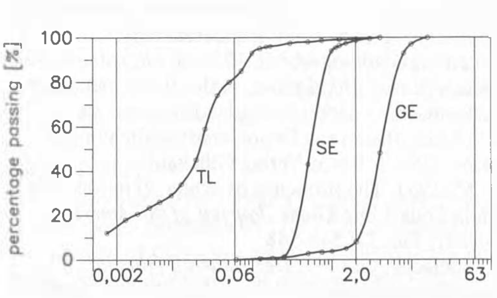

Figure 5. Grain-size distributions of the contact grains

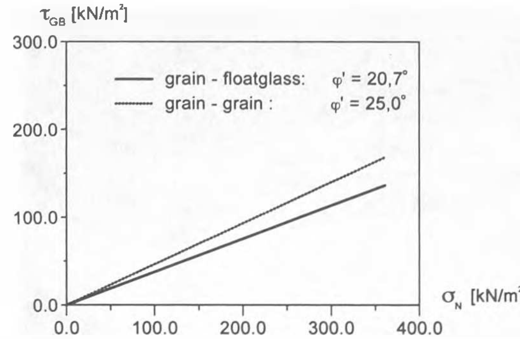

Figure 6. Shear strength in the contact area glass-grain compared to the shear strength of the soil itself

As the surface of clay liners under on-site conditions can not expected to be uniform plane the required bedding has to be ensured by a special foundation layer. Possible materials are:

1. dry mixtures with bentonite, floury kaolin clay and sand
2. bentonite cement

5.3 SHEAR TESTS

Corresponding to the on-site conditions the sealing systems of dump sites can be laid out horizontally or inclined. The acceptance of thrust and spread stresses of the sealing system from the slope has to be assured by the shear strength in the contact area between the components of the sealing systems. Investigations in direct shear tests have shown that the transmittable forces in the contact area between the flatglass-elements and the mineral layer are nearly as high as the shear strength of the mineral layer itself (figure 6).

6 TESTFIELD

To ensure the durability of the Integrated-Glass-Sandwich-Sealing the flatglass-elements have to stand the loadings during the construction of the sealing, substantially during the compaction of the covering mineral layer. The method of placement and compaction has been proved in a large scale testfield (figure 7).

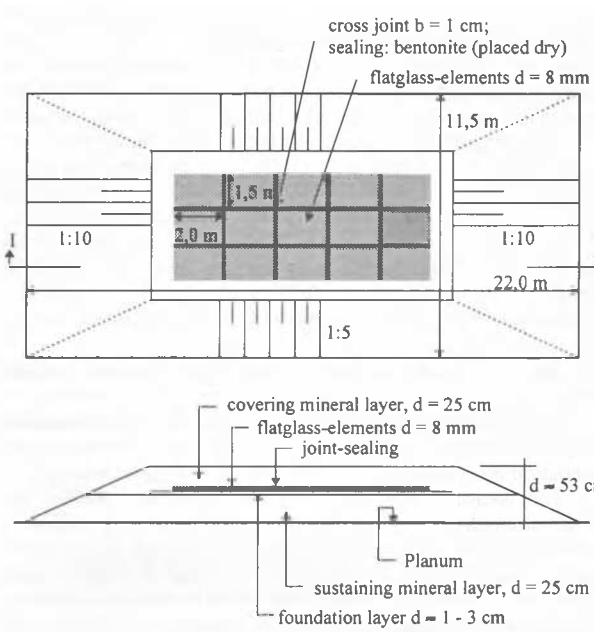

Figure 7. Plan and cross section of the large scale testfield

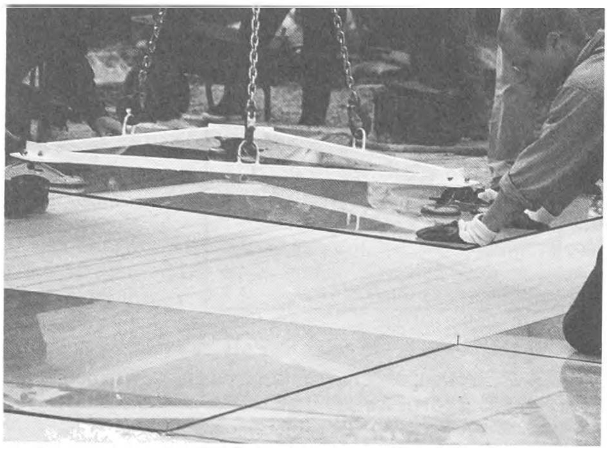

Figure 8. Placing of the flatglass-elements

Figure 9. Compaction of the covering mineral layer

After compaction the quality of the mineral layer was proved. Criteria were the water content and the density. The degree of compaction has to be greater than 95% D_{Pr} , the water content as mentioned above. Caused by the construction method the surface of the sustaining mineral layer is slightly uneven and a foundation layer is needed to bring out a uniform bearing for the flatglass-elements. We used a dry mixture of bentonite, floury clay and sand with a thickness between 1 to 3 cm, placed uncompacted. The placing of the flatglass-elements was done with a crane. The flatglass-elements were fixed with vacuum suckers on a metal frame, directed in the right position and lowered on the foundation layer (figure 8).

The exact position was ensured by temporary spacers. As glass is transparent a visual control of the uniform bearing of the flatglass-elements is possible. The sealing of the cross joints was bentonite, brought in dry. Afterwards the flatglass-elements were covered with the covering mineral layer. The compaction of the clay was static and carried out with the above mentioned tandem roller (figure 9). The loadings of the flatglass-elements during the roller crossing were continually measured by resistance strain gauges. After finishing the construction work, the flatglass-elements were exposed and proved visually.

Resuming the research at the testfield we worked out the following results:

1. All 15 flatglass-elements have been placed without breaking.

2. The covering layer has been compacted to the requested compaction degree of $D_{Pr} = 95\%$. The uniform bearing in the foundation layer ensures the durability of the flatglass-elements.

3. The measured stresses (σ_{bw}) are small compared to the design strength in case of short duration load and reached a maximum at the first roller crossing as a result of an initial loading which lead to the compaction of the foundation layer (figure 10a). Further roller crossings leads to smaller stresses of the same value, caused by regularly repeated unloadings and recharge loadings (figure 10b).

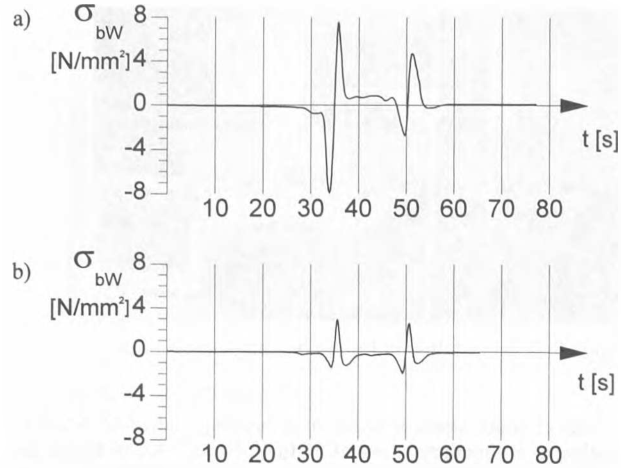

Figure 10. Bending stresses at the flatglass-element during roller crossing

4. The construction of the sealing system does not lead to residual stresses in the flatglass-elements.

5. The horizontal position of the flatglass-elements stayed unchanged.

CONCLUSIONS

1. The use of flatglass-elements is technical suitable. The strength of glass stands the expected loadcases of dump site sealing systems. A uniform bedding of the flatglass-elements is necessary.

2. Glass ensures a long-lasting sealing. The Integrated-Glass-Sandwich-Sealing reduces the impermeabilty extremely compared to the sealing systems of the German standard sealing systems stated in the TASo and TASi.

3. The introduced sealing system is only one of many reasonable sealing systems with glass. Possible improvements could be the sealing of the joints or systems with multiple glass layers.

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