Reuse of Steel Industry Slags in Landfill Top Cover Constructions

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Abstract

Many landfills in Europe have to be covered in the near future and the use of steel slags as construction material seems to be sensible. This work compiles the demands on landfill cover materials and points out problems that can occur when using steel slag in a landfill cover. There are only few legal requirements for materials used in landfill cover constructions. The most important demand on a non hazardous landfill cover is a permeability of less than 50 l m^{-2} yr^{-1}. Four electric arc furnace (EAF) slags and one ladle slag were investigated on their chemical and physical properties. One EAF slag turned out to have a high molybdenum mobility so that its use is problematic. The field capacities of some EAF slags were between 17 and 38% which is in accordance with the requirements. Ladle slag hardens fast when mixed with water which can cause difficulties in practical application.

1 Introduction

Many landfills in Europe do not meet the requirements stipulated in recent EU legislation and thus have to be closed and covered in the near future. For this, cover material is needed and the use of secondary construction material seems sensible. A reuse of steel industry slags in landfill covers is a conceivable possibility if they are cheap and easily available. However, it is unclear if steel slags meet the requirements for landfill cover materials. Furthermore, it is unknown what kind of problems can occur due to the different properties of the slag compared to natural construction material.

In co-operation with Uddeholm Tooling AB and Hagfors municipality, MiMeR (Mineral and Metals Recycling Research Centre) at Luleå University of Technology, Sweden, performs a project investigating the potential use of steel industry slags in landfill cover constructions. Parts of the municipal household waste landfill in Hagfors – a landfill for non hazardous waste - are to be covered and the slags are a potential constituent of the cover construction. Electric arc furnace (EAF) slags and ladle slag from Uddeholm Tooling AB, Hagfors, Sweden, are investigated.

This work (1) compiles the requirements that materials used in landfill cover constructions have to fulfil, (2) describes the experimental work performed within the MiMeR project and (3) adumbrates problems cropping up when reusing steel slag in a landfill cover illustrated by EAF slag and ladle slag.

2 Design of a landfill cover and demands on construction materials

In recent EU legislation, three landfill categories are defined: landfills for inert waste, for non hazardous waste and for hazardous waste (EU, 1999a). Waste to be accepted on a landfill has to match acceptance criteria based on compliance leaching tests (EU, 2002). Limit values exist, e.g. for a number of metals and salts (EU, 2002). It is desirable that construction material used in the final cover is classifiable as inert waste. If not, it should at least be in accordance with the landfill class it is covering.

Figure 1 shows a commonly applied landfill cover design. The thickness of the whole cover is at least 2.5 m. According to Swedish legislation, it must have a permeability of $\leq 50\ l\ m^{-2}\ yr^{-1}$ on non hazardous waste landfills and a permeability of $\leq 5\ l\ m^{-2}\ yr^{-1}$ on hazardous waste landfills (Miljödepartementet, 2001;RVF, 2002).

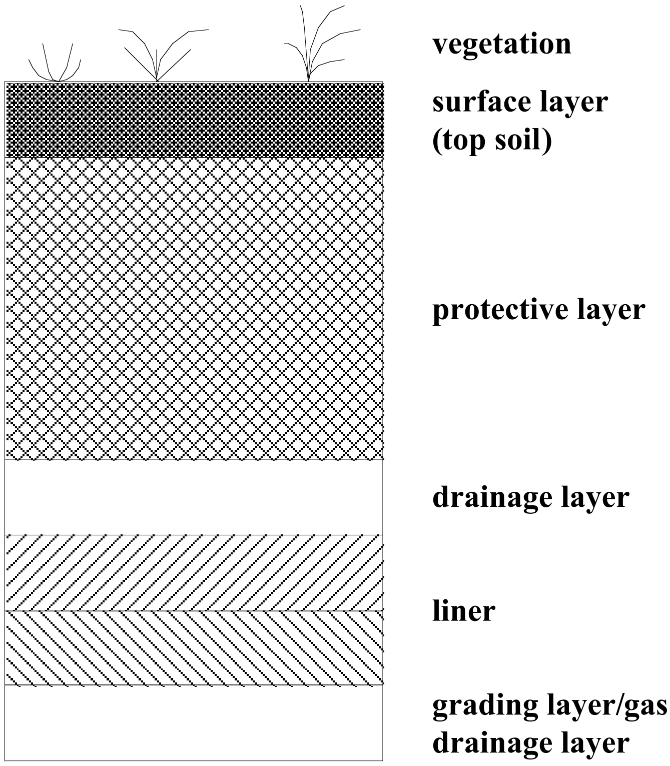

Figure 1 Design of a landfill cover with mineral liner

The **grading layer**, which is placed directly on the waste, forms a stable base for the cover construction and compensates settlements (RVF, 2002). Besides, it provides an inclination for the whole construction in the range of 1:20 to maximum 1:3 (Naturvårdsverket, 2004). It is to break the capillary water uptake from the waste. Its thickness depends on the waste structure and on settlement risks and should be > 0.5 m (RVF, 2002). The grading layer can also function as gas drainage layer (Andreas, 2002;RVF, 2002). A gas drainage layer is not mandatory according to Swedish law (RVF, 2002) but its application in final covers of non hazardous waste landfills is recommended by the EU (EU, 1999b). If it is applied it should be ≥ 0.3 m thick and have a $CaCO_3$ content lower than 10 weight-% (BRD, 1991a). The material used for the grading layer/gas drainage layer should be non cohesive, homogeneous and compactable (BRD, 1991a). Slag gravel is suggested (RVF, 2002).

The **liner** should prevent water and oxygen from getting into the waste (RVF, 2002) and landfill gas from leaking out of the landfill in an uncontrolled way. The thickness of this layer is in general 0.5 m (RVF, 2002). It has to have a low permeability so that the aforesaid permeability demands on the whole cover construction can be fulfilled. The material used should have an even grain size distribution (Arvidsson, 2001) to be well compactable because a high compaction generally goes along with a low permeability. To reach a low permeability, the material should also have a clay content of > 15-20% (Arvidsson, 2001). Bentonite is favourable for low permeability due to its swelling properties but its content should be ≤ 10% because at high bentonite contents compaction properties change (Johansson, 2003). Usually, mineral materials like clays, bentonite mats or sand-bentonite mixtures are used (RVF, 2002).

The **drainage layer** shall drain off rainwater quickly and protect the barrier layer from desiccation by its capillary breaking effect (Andreas, 2002). The application of a drainage layer on non hazardous as well as hazardous waste landfills is recommended by the EU (EU, 1999b). This layer should be > 0.5 m thick (EU, 1999b). The hydraulic conductivity should be $\geq 10^{-3}$ m s^{-1} (Andreas, 2002;BRD, 1991b). Materials suggested for this layer are e.g. coarse gravel (RVF, 2002) or sand (Rumer and Ryan, 1995).

The **protective layer** and the **surface layer** shall protect the liner from freezing, desiccation, root penetration, erosion and other mechanical influences (Andreas, 2002;Arvidsson, 2001;RVF, 2002). They are together > 1m thick (BRD, 1991a;EU, 1999b;RVF, 2002) but should be much thicker if there is risk for drying or freezing and if material availability allows. They should have a high field capacity (Gartung and Neff, 2000) which is the ability of a material to hold water against the force of gravity (ArbeitsgruppeBoden, 1994). A high field capacity ensures a high water retention and thus less water going to the drainage layer and a suitable environment for plant roots to grow. Besides, these layers shall only be slightly compacted and shall not contain leachable substances that have a negative impact on the liner or precipitate in the drainage layer. Materials usually used are silts as well as loamy and silty sands (Gartung and Neff, 2000). These two layers are recommended for both non hazardous and hazardous waste landfills (EU, 1999b). According to Gartung and Neff (2000), the following verifications and data concerning the material are needed:

- grain size distribution
- consistency limits
- proctor density
- infiltration capacity/permeability
- air capacity, water holding capacity (= available soil moisture)
- pH
- organic matter content
- lime content, iron content
- nutrient content
- hazardous substances (Gartung and Neff, 2000).

The **surface layer** shall protect the other layers from erosion. The material used should contain humic substances. A mixture of compost and structure material has been suggested (Andreas, 2002).

The landfill cover should be overgrown with plants to protect it from wind and water erosion, to minimize the infiltration of water (BRD, 1991a) and to regulate the water balance (Gartung and Neff, 2000).

3 Experimental Work

The chemical and physical analysis performed on the slags within the project includes compliance, availability and percolation leaching tests as well as an investigation of the total content of main and trace elements. Further tests are performed to determine grain size distributions, hardening, proctor density, permeability and field capacity. A full-scale field test on the landfill in Hagfors is planned for 2005. As the investigations are still ongoing, only some of the methods and results are presented in this article.

3.1 Material and Methods

Four electric arc furnace (EAF) slags and one ladle slag from Uddeholm Tooling AB, Hagfors, Sweden, were investigated. The slags were designated slag 1, slag 2, slag 3, slag 4 and slag 5 whereas slags 1 to 4 are EAF slags and slag 5 is ladle slag. Slag 1 is produced under reducing conditions and addition of silicon (Si) and recycling steel to the EAF. Slag 2 is produced under reducing conditions and addition of Si and a chromium substance with high carbon content to the EAF. Furthermore decarburization with oxygen is performed before slag separation. Slag 3 is produced under oxidizing conditions and addition of iron, molybdenum oxide, oxygen and carbon. After separation of slag 3, FeCr and FeSi are added to the EAF whereupon slag 4 is drawn off. Slag 4 and slag 5 (ladle slag) disintegrate into fine powders.

Compliance batch leaching tests were performed according to SS-EN 12457-3 correlating prEN 12457-3 (CEN, 2002) at SP (Sveriges Provnings- och Forskningsinstitut / The Swedish Sampling and Research Institute).

Hardening was tested on different slags and slag composites. Slags 1 and 2 were sieved through an 8 mm sieve. From slags 4 and 5, the very big particles contained were removed. 100g of the material was put in a plastic receptacle and mixed with water so that the mixture seemed to be well compactable. The water content was varied because the slags needed different water contents to get an appropriate consistency. The material was then slightly compacted with a metal spoon and an even surface was formed. The receptacles were covered with a lid. Hardening was checked approximately every two hours by pushing a glass rod into the material. When the rod could be pushed to the bottom of the beaker, the sample was considered not to have hardened, when the rod could not be pushed in completely or not at all, the sample was considered to be hard.

Field capacity was tested on EAF slags 1, 2 and 4. The ladle slag was not tested because it hardens so fast that it was not possible to perform the test. Each sample was placed -

in several layers - in a plastic tube that was closed with a lattice and a filter at the bottom. Each layer was slightly compacted using the bottom of a plastic beaker. Two different tubes were used with a diameter of 14 cm and 9.3 cm, respectively. The height of the samples in the tubes differed between 14 and 17.5 cm. The tubes were placed in a water bath where they were allowed to soak water for approximately one hour until the water level inside the tubes had reached the one outside. They were then taken out of the water bath so that water could drain off the samples for two to six hours. The samples were weighed in dry and wet state.

3.2 Results

The results of the compliance batch leaching tests show that the molybdenum (Mo) mobility in slag 3 exceeds the EU limit values for non hazardous waste (EU, 2002) (table 1). All other slags meet the limit values for non hazardous waste.

Table 1 Results of the compliance batch leaching test presented as averages (n = 3) compared to the limit values for non hazardous waste stipulated by the European Union (EU, 2002) (mg (kg TS)$^{-1}$)

com-ponent	slag 1		slag 2		slag 3		slag 4		slag 5		limit values	
	L/S 2	L/S 10	L/S 2	L/S 10	L/S 2	L/S 10	L/S 2	L/S10	L/S 2	L/S 10	L/S 2	L/S 10
As	0.01	0.045	0.01	0.03	0.02	1	0.01	0.6	0.01	0.03	0.4	2
Ba	0.73	1.8	0.01	0.07	0.05	0.1	0.9	0.23	1.8	1.2	30	100
Cd	<0.003	<0.003	<0.003	<0.003	<0.003	0.003	<0.003	<0.003	<0.003	<0.003	0.6	1
Cr	0.15	0.2	0.08	0.17	0.07	0.55	<0.005	<0.005	<0.005	0.005	4	10
Cu	0.01	0.03	0.01	0.03	0.04	0.1	< 0.01	0.03	< 0.01	0.03	25	50
Mo	2.7	4.7	3.4	7.7	**10**	**100**	0.08	0.6	0.02	0.1	**5**	**10**
Ni	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	5	10
Pb	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	5	10
Sb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.2	0.7
Se	0.06	0.18	0.03	0.09	0.02	0.08	< 0.02	0.05	0.07	0.15	0.3	0.5
Zn	0.01	0.02	0.06	0.07	0.1	0.11	0.02	0.1	< 0.01	0.1	25	50
Hg	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.05	0.2
F^-	8.9	25	9.7	31	15	55	2.6	7	2.5	5.4	60	150
Cl^-	7	9	4.6	5.7	1.6	3	< 1	2.3	< 1	10	10000	15000
SO_4^{2-}	24	57	17	5.3	< 1	10	< 1	< 1	< 1	5	10000	20000

The hardening tests show that EAF slag 4 gets hard after 8 hours or more after mixing with water. EAF slags 1 to 3 do not harden within one day. The ladle slag (slag 5) becomes hard after 4 to 6 hours. The admixture of 30% to 40% EAF slag to the ladle slag decelerates the hardening process to more than 8 hours.

Results of the field capacity tests are shown in table 2.

Table 2 Results of field capacity tests performed on the EAF slags

	Slag 1	Slag 2	Slag 4
Field capacity [mass-%]*	7.2	7.8	17.6
Field capacity [vol-%]	16.9	18.7	37.5

*calculated by dividing the mass of the contained water by the total mass of the wet sample

4 Discussion: Difficulties that might occur when using Steel Slag as Construction Material in a Landfill Cover illustrated by EAF and Ladle Slag

Legal requirements for materials used in landfill covers are rare. Demands on construction material cited in chapter 2 are mostly recommendations given in technical guidelines that are often unassertive. Hence, the assessment of the suitability of a potential cover material and the decision of which tests and verifications to make are mainly based on experiences.

As slag 3 does not comply with the EU limit values for non hazardous waste, it will not be comprised in the cover of the Hagfors landfill for non hazardous waste unless it is treated to lower the Mo mobility. All other slags fulfil the EU limit values for non hazardous waste (EU, 2002) and can possibly be reused in the cover. However, landfill cover construction materials should preferably fulfil the criteria for inert waste to prevent any harm to the environment. If this is not the case, water percolating through the cover should be collected and treated until the mobility of the respective substances from the slag has decreased to acceptable rates. Such leachate treatment certainly increases the post closure care costs. The duration of the treatment depends on the concentrations and mobility of the critical substances and on the environmental conditions in and around the covered landfill.

The ladle slag is a very fine material that probably has cementitious properties. Mixed with water and compacted, it might be used for the liner - assumed that the permeability is appropriate. Hardening tests on this slag showed that it hardens quickly which is adverse for its application as construction material because its use is tightly time bounded. However, the admixture of EAF slag 1 or 2 seems to decelerate the hardening process enabling its application for at least one working day. Although EAF slag 4 is also suspected to have cementitious properties, it stays soft for more than eight hours after mixing with water which means that it is practically applicable. However, if these slags are really suitable as liner materials can only be assessed after their permeability has been tested.

EAF slag can possibly be applied in the protective layer of the cover. This layer is required to have a high field capacity. The field capacities of the EAF slags were determined to be between 17 and 38 vol-%. Materials commonly used in this layer are silts and loamy and silty sands (Gartung and Neff, 2000) which have similiar field capacities (ArbeitsgruppeBoden, 1994). However, the material used should contain organic matter for better stability and root growth. Thus, EAF slag alone cannot be used for this layer but it is conceivable to admix it with another material, e.g. sewage sludge, compost or soil.

The long term behaviour of these slags in a cover construction, concerning physical and chemical stability, is still unknown. As the use of steel slag in landfill covers is not common yet, there are probably only few practical applications to refer to so that authorities and landfill owners being in need for cover material might not show confidence in steel slags. Hence, the planned full-scale field test will be an opportunity to test the materials and to examine their usability.

5 Conclusions

Only few legal requirements for materials used in landfill cover constructions exist. However, there are many recommendations that are often unassertive. Thus, it is difficult to assess if a material is suitable for a landfill cover.

In one of the investigated EAF slags, Mo mobility was so high that this slag can probably not be used in a landfill cover. For ladle slag, the quick hardening can cause difficulties in practical application. The hardening of ladle slag could be decelerated by admixing EAF slag.

Properties of both EAF and ladle slag are not sufficiently examined yet. Hence, future research includes the study of a full scale test at Hagfors landfill. Among the factors to study are mechanical stability, physical and chemical properties including long term stability, permeability of the whole cover construction, leaching of contaminants and functioning of the constituent layers.

Acknowledgements

The financial support of MiMeR (Mineral and Metals Recycling Research Centre), Uddeholm Tooling AB and Hagfors municipality is gratefully acknowledged.

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