PHYSICAL PROPERTIES OF STEEL SLAG TO BE REUSED IN A LANDFILL COVER

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SUMMARY: Many landfills in Sweden as well as in Europe have to be closed in the near future. Apart from material costs in the order of tens of billions Euro, this puts a strain on the environment through the exploitation of virgin materials. Many landfill operators are considering alternative cover constructions in order to reduce resource spending. In this study, the authors are looking at a construction including slags from a steel mill. Four electric arc furnace (EAF) slags and one ladle slag from Uddeholm Tooling AB at Hagfors, about 270 km Northwest of Stockholm, were investigated with regard to their physical properties. A full scale field test on an area of about 5,000 m^2 will be started at the local municipal landfill in Hagfors in August 2005.

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. Roughly 2,000 hectares of landfill area in Sweden have to be covered, equivalent to almost one hundred million tonnes of construction material. In order to minimize the exploitation of virgin materials, secondary materials are often considered to be a sensible alternative. Steel industry slags could be a conceivable possibility if they are cheap and easily available. However, no studies are known looking at the behaviour of steel slags in this special area, e.g. what kind of problems may occur due to the different properties of the slags compared to conventional construction material, if the slags will meet the requirements for landfill cover materials, and how they will perform in the long run.

In co-operation with Uddeholm Tooling AB and Hagfors municipality, the Division of Waste Science & Technology and MiMeR (Mineral and Metals Recycling Research Centre) at Luleå University of Technology, Sweden, perform a project investigating the potential use of steel industry slags in landfill cover constructions since autumn 2004. Parts of the municipal 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.

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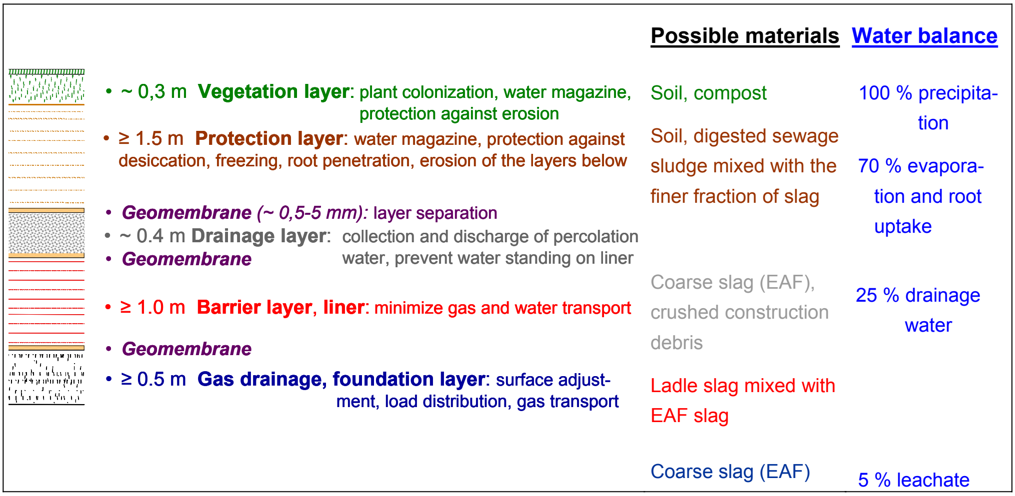

Figure 1. Layers and their function in a cover construction with a mineral liner; examples for possible alternative materials and water balance for the different layers.

2. CONSTRUCTION OF A LANDFILL COVER SYSTEM

A final cover construction is a system of components that all contribute to achieve the desired function. The legal requirement in Sweden is directed towards the maximum amount of leachate generated: < 5 and < 50 l $(m^2 * a)^{-1}$ for landfill class 1 and 2, respectively (SFS 2001:512). The functions of the single layers within the cover are described in Figure 1.
The figure also gives examples of possible alternative construction materials and of how the different layers influence the water balance.

The field test at the Hagfors landfill will include a number of alternative cover constructions with varying design of the barrier layer. The construction activities will start in August 2005 and be finished during 2006. A similar project investigating an alternative cover construction including ashes from the incineration of refuse derived fuel (RDF) and biofuel, is performed at the Tveta landfill outside Stockholm (Tham et al., 2003 & 2005; Travar et al., 2005).

3. METHODS AND MATERIALS

The evaluation of the function and long-term durability of the cover construction has to be made in both lab and full scale. Swedish legislation prescribes only elementary analysis and short-time leaching tests for material characterization (NFS 2004:10). Simple leaching tests can indicate if the material contains substances that leach under the chemical conditions of the used test. They are not pH- or redox controlled and hence do not reveal information about the interaction of the tested materials with other materials. The short time of the test prevents the observation of processes governed by biological reactions in the sample. Though some of the tests are performed at high L/S[1] ratios the significance for the long-term behaviour is reduced to the leaching of e.g. salts and other components that do not change their behaviour over time and/or depending on the environment (Andreas, 2000).

[1] L/S ratio – liquid to solid ratio

Table 1. Annually output of the different slags from the Uddeholm Tooling steel mill

slag	EAF 1	EAF 2	EAF 3	EAF 4	LS
amount [ton/a]	5,200	2,000	2,500	800	1,300

In order to make more realistic predictions a combination of different assays must be used (Kylefors et al. 2003). Also, predictive models must be validated through field observations. Many detail issues are to be studied in the over all evaluation of the landfill cover such as:

- How do the different parts of the structure affect the water balance?
- How are landfill gas emissions affected by and interacting with the liner?
- How is the construction affected by landfill settlements?
- What reactions take place as water percolates through the different layers?
- How should the water above the liner be treated and for how long?
- What are the impacts of external and landfill internal processes on the liner?

During the field test, also mixing procedures and different standard contractor equipment (compacting technique, lay-out procedures etc) are tested. The field tests are the predominant part, including monitoring and sampling from the experimental area (water quantity and quality, gas quality, temperature, settlements; compare Tham et al. 2003 and Travar et al. 2005).

The lab tests include material characterization (elemental analysis; compliance, availability and percolation leaching tests), grain size distribution, curing properties, proctor density, hydraulic conductivity and field capacity. For the assessment of the future development of both function and emissions, also the long-term behaviour will be investigated using physical models (e.g. 80-liter-vessels). A mineralogical characterization of the materials using X-ray diffraction as well as SEM and IR-techniques will give answers regarding reactions of the liner materials with gas and percolation water. How the materials interact within the liner after being mixed with water will be studied with the same type of techniques, in both short time and long time perspective.

Four electric arc furnace (EAF) slags and one ladle[2] slag from Uddeholm Tooling AB were tested. The slags are referred to as slag 1 to 5 whereas 1 to 4 are EAF slags and 5 is the ladle slag. The annually output of the different slags is listed in Table 1.

Slag 1 and 2 are produced under reducing conditions; slag 1 under addition of silicon (FeSi) and recycling steel, slag 2 under addition of FeSi and a chromium substance with high carbon content to the EAF. Furthermore, slag 2 is decarburized with oxygen before slag separation. Slag 3 is produced under oxidizing conditions and addition of iron, molybdenum oxide, oxygen and carbon. After the separation of slag 3, FeCr and FeSi are added to the EAF whereupon slag 4 is drawn off. The steel is treated further at the ladle station and new slag former is added. The treatment at the ladle station occurs under reducing conditions. Slag 4 and 5 disintegrate into fine powder because of the high ratio of Ca/Si.

4. RESULTS AND DISCUSSION

4.1 Grain size distribution

Figure 2 shows the grain size distribution of the tested materials. The EAF slags 1, 2, 3 were crushed to a size smaller than 20 mm at Uddeholm Tooling AB. The sieving shows that they have a very similar grain size distribution. Moreover, they are much coarser than EAF 4 and

[2] Ladle: a vessel for transporting molten metal in a foundry

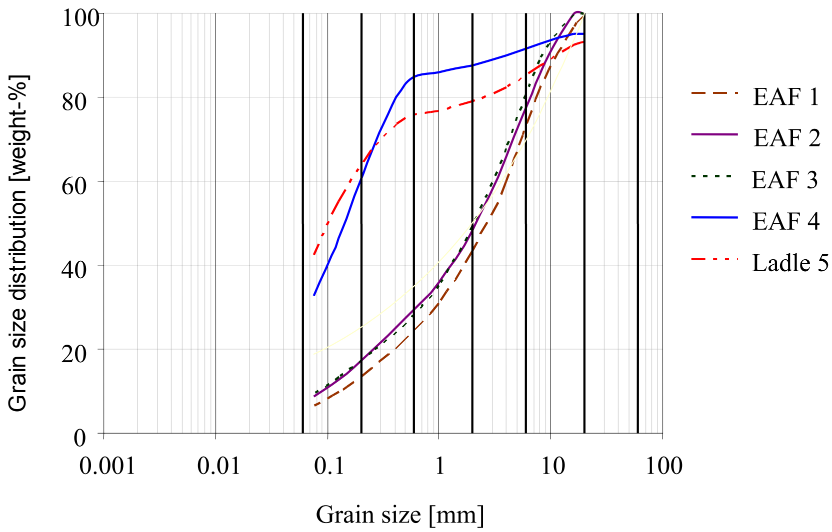

Figure 2. Grain size distribution of the tested materials.

ladle slag 5 with only 16 to 20 weight-percent of the particles being smaller than 0.25 mm and 50 % smaller than 2 mm. Even though slag 4 and 5 are different in terms of their generation process they have a number of similarities, to begin with they have similar grain size distributions with two thirds of the particles in the fraction < 0.25 mm. This makes them to a first choice material for the liner within the cover system since the fine structure is a basis for good compaction properties and low permeability values.

The EAF slags 1-3 are intended to be used in the drainage layers. For this purpose the crushing mesh size may be chosen bigger than 20 mm, for example 16/32 mm. However, as described further down, a part of the material is also needed for admixture to the fine slags in the liner in order to decelerate the curing process. The finer fraction generated during crushing seems to be useful for this.

The laboratory tests described below were performed with the fraction < 8 mm of the different materials.

4.2 Curing and compaction properties

The curing behaviour and the proctor density of the slags and different mixtures to be used in the liner were tested.

Curing (after mixing with water) is a special feature of ashes and slags that have cementitious properties which differentiates them from materials conventionally used in landfill covers. Slag 1, 2 and 3 can be described as gravel-like, i.e. they are quite coarse (compare Figure 2) and do not cure. Slags 4 and 5 have curing properties: Without compaction slag 4 is pliable for some time (days if not desiccated) whereas slag 5 hardens to a rock-like consistency after a few hours. The curing of the slags contributes to an increased mechanical stability and a low hydraulic conductivity of the materials. Yet, it should not proceed too far before the material is in place and compacted. For that reason, slags with different properties were mixed in order to achieve a slower and less powerful curing process. Admixtures of 35 to 55 % of EAF slag to the ladle slag resulted in satisfying sample consistency after up to 24 hours.

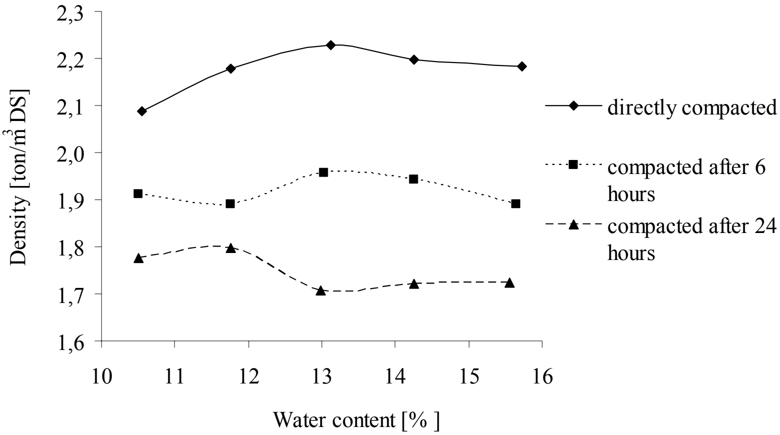

Figure 3. Variation in Proctor density and optimum water content depending on the point of time of compaction related to the addition of water for ladle slag + 35 % EAF 1

The curing properties of the materials have an impact on the compaction properties. Different optimum water contents and maximum densities were expected depending on how long time passes between the addition of water to the samples and the compaction. In practice, a period of about 8 hours will probably be the maximum, assumed that the material for a whole working day will be prepared at once e.g. in the morning. Therefore, the proctor tests were performed at three different points of time after the addition of water: (1) directly after the admixture of water, (2) 6 hours, and (3) 24 hours later. The proctor densities were in the range of 1.9 to 2.3 t/m^3 TS, depending on time and water content. Figure 3 shows the variation of the compaction properties instancing the sample “Ladle slag + 35 % EAF 1”. Longer time between water addition and compaction seems to result in lower densities and the highest density for each curve is achieved at a lower water content compared to direct compaction.

When higher admixtures of EAF (45 and 55 %) were applied the achievable maximum densities increased by about 5-10 % which basically depends on the higher density of the EAF. The optimum water content decreases with increasing admixtures. Compared to soils, the range of possible water content is quite narrow.

4.3 Hydraulic conductivity

The tests for the hydraulic conductivity of the material mixtures were performed according to a factorial design. The investigated factors and their levels are listed in Table 2.

Table 2. Investigated factors and their levels

Level	Factors		
	A share of admixture of electric arc furnace slag	B water content during compaction	C time between adding water and compacting
Low	35 %	9 %	0 h
Centre	45 %	11 %	6 h
High	55 %	13 %	24 h

The experimental equipment did not allow more than 10 runs at the same time. Therefore, the experiment was run as an unreplicated full factorial design with two center points which results in $2^3+2 = 10$ runs. The run order was fully randomized. The running time of the tests was extended to about 12 weeks compared to about two to three weeks for soil or clay samples. Yet, for some of the samples the flow did not become stable. Four samples had a permeability smaller than the lowest measurable value, i.e. $< 2.2*10^{-11}$ m/s but for the statistical evaluation all the four values were set to $2.2*10^{-11}$. The hydraulic conductivity of the other samples was the range of $1.4*10^{-8}$ and $4.5*10^{-11}$ m/s, on average $3.5*10^{-9}$ m/s.

Due to these experimental difficulties and due to the lack of replicates, the resulting statistical model was very weak. Yet, it could be seen that an increase of the factors A and C leads to an increase of the permeability. Hence, EAF should be admixed moderately and the time span between mixing and compacting should be kept as short as possible.

According to Swedish legislation, the hydraulic conductivity for a cover system for a landfill for non hazardous waste must not exceed 50 litres per square meter and year. As described above, the cover system consists of a number of different layers that all contribute to achieve the desired function. As can be seen in Figure 1, the largest reduction of potential leachate formation occurs in the layers above the liner, depending on design aspects like the relative permeability of the different layers, their slope and the pipe and trench system design. The covers used are designed to allow only one percent or less of the yearly precipitation to form leachate.

5. SUMMARY AND CONCLUSIONS

Research work on steel work slags as secondary construction materials is in its initial phase. The available results show that:

- It is possible to use the tested steel slags in a landfill cover construction. They can be used in all layers apart from the vegetation layer.
- Only EAF slag 4 might be used as a single material in the liner while the ladle slag needs to be mixed with one (or a mixture) of the EAF slags 1, 2, 3 in order to decelerate the curing process and thereby make it workable.
- The possible range of optimum water content for compaction is quite narrow which makes it necessary to adjust the water content closely.
- However, the water content does not seem to affect the hydraulic conductivity to the same degree.
- The compactibility deteriorates with increasing time between the addition of water and the compaction.
- The cover construction is expected to fulfil the regulations with regard to permitted leachate generation. The full scale test will give knowledge about how the materials work under field conditions.
- Much research is still required in order to show the impact of the slags in the long term.

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