

## **Steel Slag. Conversion of an industrial waste material into a value adding asphalt ingredient.**

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Modern steel plants use scrap steel in their productions. Electric arc furnaces (EAF) are used to recycle significant quantities of steel.

For each ton of steel an EAF produces about 130 to 180kg of a very particular electric oven slag (EOS) as waste product. This slag has few uses and is a material that is produced each year in large quantities and much of it is deposited in landfills.

After curing thin layers in large open beds the slag can be used to manufacture valuable mineral aggregates for asphalt production. The slag needs to be crushed in impact mills and graded to size. These aggregates have a cubic form and a rough surface. High impact crushing strength, high polished stone value and good affinity to bitumen due to basic nature of surfaces make this material ideal for asphalt production. Experiences over 20 years have proven that Asphalt containing EOS performs well. Skid resistance is maintained at high levels over time, deformation resistance is enhanced and the good affinity between aggregate and binder extends surface life under difficult North European conditions. The climate is characterized by freeze-thaw cycles in winter, frequent rains in the rest of the year but also high asphalt surface temperatures well above 60°C in summer.

Formulating EOS into asphalt provides a considerable sustainability advantage by relieving the need to use landfills and avoiding exploitation of minerals from natural resources. Used in proximity to the steel works also transport of minerals over long distances is avoided. Above all these economic and ecological benefits EOS in asphalt actually adds technical value by delivering enhanced asphalt performance.

### **Introduction**

Protection of the environment and responsible use of natural resources are topics that is being discussed in politics, economy and academia. All media e.g. TV, radio, print or Internet have made it one of their priorities.

In many industries not only valuable products are turned out, production of waste product is often inevitable. Often these waste products have to be discarded. As costs of depositing anything in landfills or to dispose of matter by alternative routes are steadily increasing there is a constant push to try and find sustainable uses for such product.

Steel production is synonymous with industrialisation and huge quantities of steel have been produced since the industrial age started. Steel production is coupled with the production of slag. Slag is constituted of all non metallic mineral components contained in the ores and other raw materials for steel, This means that the need to find a solution for huge amounts of slag coming from this production is almost as old as steelmaking itself.

The use of slags as raw materials in the building industry is quite logical as this industry uses huge masses of mineral substances. To integrate such products into the volume streams for construction activities is reducing the volumes of materials

going into landfills and also protects natural resources like quarries for valuable hard mineral aggregate.

In Germany there is also the need to comply with a national law that enforces avoidance of waste and requires that only materials that have no alternative use can be discarded. If such alternative uses exist, they must have preference over the use of new materials.

The use of steel slag in asphalt production is described in this paper.

## 1. Production

Steel or iron slag can be called "man-made crystalline stone" obtained from the non metallic fraction of the melt produced in steelworks. It is separated from the metallic material and cooled down to ambient temperatures. The making of slag is actually quite similar to the creation of natural magmatic minerals such as basalt and granite. Slags have to be clearly separated from other products of incineration, especially ashes.

In the beginning of iron making the slag had to be separated from metal by hammering it off. The name slag is derived from the Germanic term "to beat". Today slags are already separated in liquid phase from metal in the melting process due to its lower density. Specific cooling processes and conditioning make it possible to deliberately influence and determine properties of the slag.

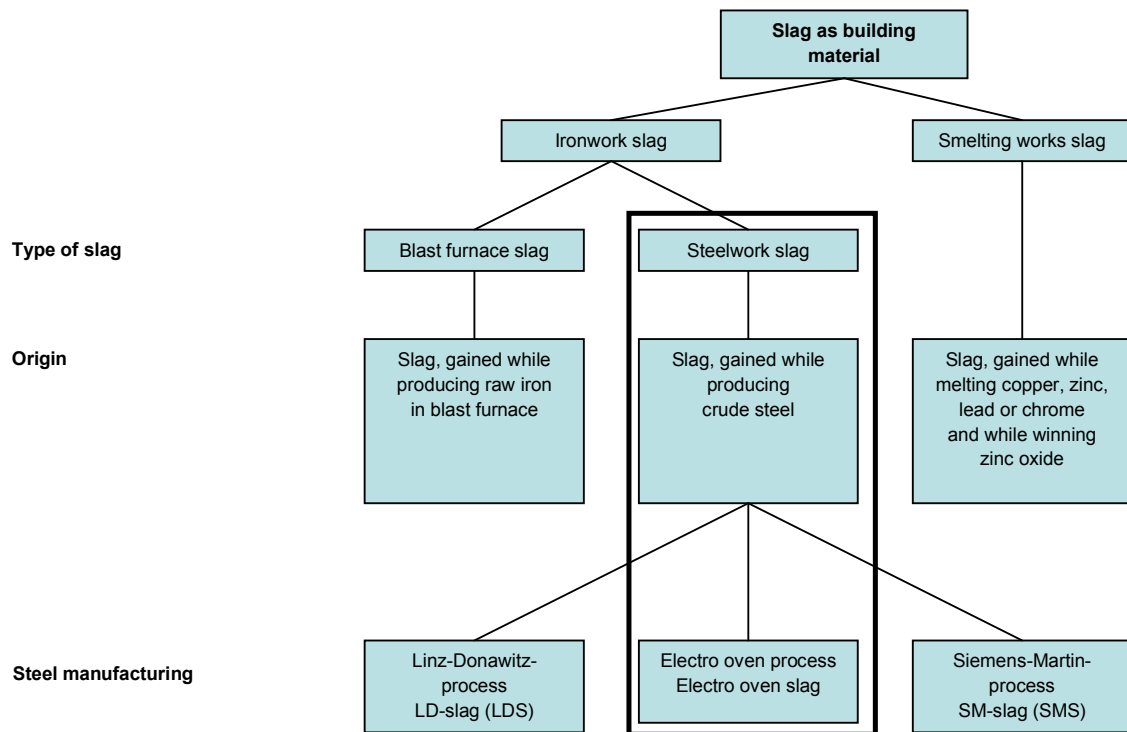


Fig 1: Categorisation of slags according to production process

A closer look reveals that steel slag is made at approx. 1650 °C when raw iron, iron sponge (direct reduced iron) and scrap metal are converted into steel. It contains not

only the non metallic components from iron ore or other additives, also calcium carbonate and dolomite that is added in steel manufacturing ends up in the slag. Steel slag is classified in Germany according to the steel production method it is produced with. LD-slag is produced by the Linz-Donawitz-Method. The other important category is EO-slag or EOS, coming from Electric arc furnaces, also named electric ovens. These two products are the ones available to the market. The slag is either slowly cooled down in beds (fig.2) and weathered for some time to reduce the reactive potential of unbound calcium carbonate or quartz sand or oxygen are added to the molten slag to bind the calcium carbonate so that the weathering becomes obsolete.



Fig2: Steel slag poured into a cooling bed  
Picture: Leyla Cakar

Selective and guided cooling can influence the physical properties and the grain size of the slag to make it suitable for very different intended uses.

Research of slag use in asphalt mixes experience has shown that a relatively high residual content in LD-slag poses problems for the volume stability of coarse aggregates produced from it. Exposure to moisture impairs the strength of the minerals. EOS on the other hand is manufactured with a process that results in low content of residual calcium carbonate in the slag. Its volume stability is far superior to LD-S and the product has constant quality while LD-S shows significant variations in volume stability between batches.

Another strong reason to focus on EOS is the fact that steel slag can contain high contents of Chrome and Vanadium. The EO process and the conditioning of the slag minimize the risk that these substances are located in the slag in a way that they can be eluted and migration into ground water becomes a probability. Eluate testing is established as part of quality control for EOS.

Over the past 50 years the amount of slag has been steadily reduced through process optimisation from approx. 200 kg per ton to now 120 kg per ton of steel. It would appear unlikely that this ratio would be reduced further.

## **2. Crushing and grading of the slag**

After cooling (and, where appropriate, weathering) the slag is removed from the cooling beds with big front end loaders and stockpiled.

High quality crushers and grading machines are used to produce different defined aggregate sizes for application in asphalt mixes. A pre crusher prepares the material for the main crushing process. Before the slag enters into the main crusher magnets remove residual iron still contained in the slag.

The process used to condition the slag for use in road building is similar to the technology used to break and grade natural mineral aggregates to defined shapes and sizes.



Fig.3: Grading machine for crushed steel slag  
Picture: Leyla Cakar

### **3. Properties of the slag**

Steel slag is acknowledged in the building industry to be a valuable raw material because of its inherent excellent properties:

#### **High stability**

Steel slag is an artificial stone with very high maximum specific density and very high stability. Due to a low impact crushing strength and high compressive strength they are ideal for use in high deformation-resistant asphalt designs.

#### **Skid resistance**

High quality chippings made from steel slag have a very rough surface texture. Used in wearing courses they will deliver good skid resistance. This can be further increased by use of crushed sand made from steel slag (0/2) mm

#### **Polished-Stone-Value**

EOS chippings have a PSV-value < 55

## Cubic form

The cubic form of the aggregates does not only add stability in mix designs, it also has a positive impact on tyre noise. .

## Affinity to bitumen

Steel slag has excellent affinity to bituminous binders. 10% steel slag content in the mineral components can be used to lower binder content by 0,1 to 0,2 %.

## Comparing steel slag /Norwegian Granite

		EOS	Granite	Standard
Maximum density	g/cm <sup>3</sup>	3,5	2,7	
Los Angeles coefficient	m-%	14	24	≤25
Impact crushing strength	m-%	10,6	17	≤18
Polished Stone Value (PSV)		56	54	≥50
Freeze-Thaw-Resistance	m-%	0,3	0,3	≤8
Thaw resistance	m-%	0,1	0,2	≤1
Heat resistance	m-%	0,3	0,1	n.a.
Affinity aggregate to bitumen rolling bottle	%	85	70	n.a.
damaging fines (Methylene blue)	g/kg	1,7	1,67	≤10
Particle shape value	SI	3	15	≤15

Fig.4: Comparison of steel slag to Norwegian Granite, a standard material used in the North of Germany  
Source: Quality assurance data of Hamburger Stahlwerke, Germany and Espevig quarries, Norway

## 4. Specifications and regulations

Already 1941 the German norm DIN 4301 „Eisenhüttenschlacke und Metallhüttenschlacke im Bauwesen“ (iron- and metalworks slag in the building industry) was published. It describes the properties of slag and sets standards to comply with. The use of steel slag is further regulated via the specifications that deal with the quality of mineral aggregate for asphalt manufacturing.

Triggered by European normalisation steel slag became part of the specification for mineral aggregate which in Germany is found in the document "Technische Lieferbedingung Gestein-StB 04 (TLG-Stb 04)" that deals with the relevant test methods and norms. It also regulates the frequency of mandatory testing and certification by independent laboratories. Furthermore the specification elaborates on the criteria for internal quality assurance for quarries or in this case the part of the steel works that deals with bringing the slag to market. TLG-Stb04 requires that steel slag has to be certified by means of a complete set of analysis every six months.

## 5. Use in asphalt mixes

It was decided in 1991 to launch a comprehensive procedure to test the suitability of steel slag for asphalt formulations in the field. EOS was used in asphalt layers and unbound road bases. Monitoring of test sections has produced the insight that the use of EOS has no negative effect and that due to its properties it can improve the deformation resistance of asphalt, especially in roads carrying high axle loads.

EOS also became part of a study on the skid resistance of asphalt wearing courses in 2002. A study was commissioned with the independent institute IFB/Gauer to determine how minerals with good surface texture influence the skid resistance of whole surfaces. Because EOS is classified as such a mineral aggregate it became part of the study. The research was performed on stone mastic asphalt because this mix type can display a significant decline in skid resistance over time.

The following mixes were evaluated against each other:

- A SMA 0/11 S with 100 % EOS chippings
- B SMA 0/11 S with 100 % quartz-porphry chippings
- C SMA 0/11 S with 11% EOS chippings, rest with quartz-porphry
- D SMA 0/11 S with 100 % quartz-porphry chippings and EOS crushed sand

The binder for all mixes was a 45 PEN polymer modified bitumen (PMB 45).

IFB/Gauer tested these samples on a stationary testing apparatus. This setup can be correlated to measurements with the SCRIM tester that at the time of the research was the official machine used to determine performance of newly built asphalt surfaces against contractual specification.

Trial set up (descriptive):

The polishing of surfaces by tyres is simulated with rubber elements that are mounted on a rotating polishing disk. These rubber elements contain quartz sand to accelerate polishing. The slip necessary for a polishing action is introduced by a horizontal oscillating movement of the disk.

The rotating disk is braked by the rubber elements sliding over it simulating a slipping tyre. The force transferred from the rubber elements into the surface is measured and calculated into a prognosis value PGM (this value is then correlated to SCRIM). To meet compliance standards for SMA after 4 years this test has to be run for 20 minutes. The PGM is not allowed to be lower than 0,53. The trial is then run for a total of 3 hours to simulate life of the surface. Here it was determined that failure is considered to be a PGM lower than 0,49. The results are displayed in Fig. :

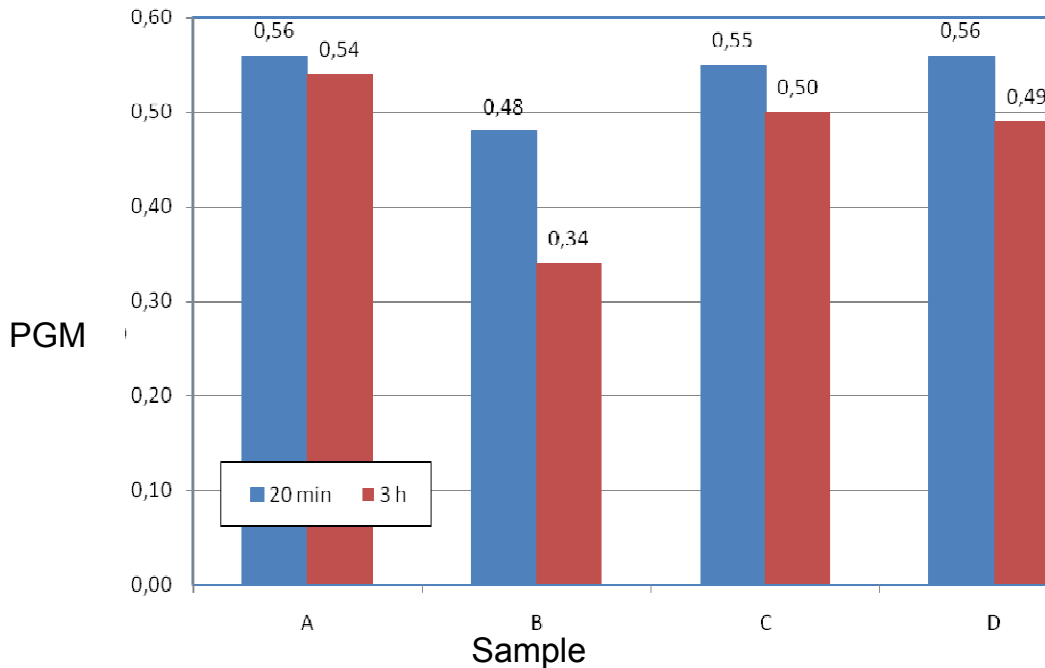


Fig.5: Prognosis value PGM found in comparative skid resistance trialling  
 Source: IFM/Gauer, Verbesserung der Griffigkeit von Splittmastixasphaltdeckschichten durch Elektroofenschlacke, Regenstauf 2002

The samples were also subjected to the Hamburg wheel tester to determine their deformation resistance:

Sample #	Rut depth
A	2,5 mm
B	4,0 mm
C	2,9 mm
D	3,1 mm

Summary of the research:

1. All Asphalt mixes with EOS have either good or very good performance according to the PGM values found in the trial.
2. Asphalt mixes formulated with low PSV can be significantly improved with addition of EOS.
3. Addition of crushed sand made from EOS also significantly improves skid resistance.
4. EOS improves deformation resistance.
5. Visual inspection of the Hamburg wheel tracker samples show that the samples with EOS show significantly less stripping.

These test results lead to a successful introduction of EOS products for the asphalt industry in the northern part of Germany in 2003. The slag is manufactured by the Hamburger Stahlwerke where the necessary technical procedures to make quality product for asphalt were established. This is the region with which the authors are familiar. Steel slag for use in road building is by now also produced in Southern Germany and in the Ruhr area where suitable steel works are located.

By today about 5.000.000 tons of asphalt have been produced in northern Germany containing EOS from the Hamburger Stahlwerke. Twenty-one asphalt plants are using the products in many different mix designs.