Proceedings of the Fourth International

Slag Valorisation Symposium

Zero Waste

15-17 April 2015
Leuven, Belgium

Editors Annelies Malfliet and Yiannis Pontikes

KU LEUVEN

ELECTRIC ARC FURNACE SLAG ENGINEERING DURING PRODUCTION, TREATMENT, SOLIDIFICATION AND PROCESSING

Susanne SCHÜLER[1], Hans-Peter MARKUS[2], David ALGERMISSEN[3], Dirk MUDERSBACH[3]

[1] Max Aicher Umwelt GmbH, 86405 Meitingen, Germany
[2] Lech-Stahlwerke GmbH, 86405 Meitingen, Germany
[3] FEhS-Institut für Baustoff-Forschung e.V., 47229 Duisburg, Germany

s.schueler@max-aicher.de, hans-peter.markus@lech-stahlwerke.de, d.algermissen@fehs.de, d.mudersbach@fehs.de

Introduction

In 2014 the total production of EAF slag in Germany was around 2 M tons for both quality and high alloyed steel production.[1] Worldwide the production of EAF slag is estimated at more than 200 M tons.[2] Today EAF slag in Europe is well characterized and used as construction material. There is a long tradition of using especially ferrous slag as manufactured aggregates. In recent decades its use as a building material has gained in significance and currently in Germany 3/4 of the production of EAF slag is used for this application.[1] There is vast experience in using EAF slag as aggregates for road construction, as armourstones for hydraulic engineering and in other applications throughout Europe (e.g. aggregates for concrete).

EAF metallurgy

These numerous fields of applications can only be achieved because the steel works influence the quality of the EAF slag in every process step, starting with the selection of input materials. These have the major influence of the chemical slag composition, e.g. different types of scrap and slag formers.

In this step, it is very important for the slag quality that lime and other slag formers are dissolving completely in the melt. Otherwise free oxides could be found later in the slag, which will generate hydroxides with water contact, resulting in volume increase (Formula 1 and 2). This could lead to a non volume-stability later in application, which is required in many cases, especially in bounded bearing layers.

$$CaO_{free} + H_2O \rightarrow Ca(OH)_2 \quad [\Delta V\uparrow] \tag{1}$$

$$MgO_{free} + H_2O \rightarrow Mg(OH)_2 \quad [\Delta V\uparrow] \tag{2}$$

To investigate this mechanism, the steaming test is an established method to describe the volume expansion by building free oxides and to verify the quality of the slag.

To reduce the risk of unsolved slag formers it is possible to add lime as fines, e.g. by injection. The higher surface of the fine material has a higher reactivity and a higher possibility to dissolve it in the melt. The positive side-effect is a homogeneous circulation in the melt.

Chronologically, the next influence factor is the melting process itself, with different possibilities of the furnace operation e.g. influence of oxygen and coal or of tapping after melting process. It is responsible for the homogeneity of the slag, because of different operation steps while slag is already tapping.

Environmental behavior

In particular the cooling is also an important influence of the environmental sustainability of the slag, which is responsible for using EAF slag, regarding the current standards[3], because in this step different mineral phases are generated.

One parameter for the importance of mineral phases is *VANADIUM*. It is bound in lime silicates which are solvable in water, if no other/not enough lime bonds are solved before. This can be influenced during the melting process by adding lime media, e.g. slags from secondary metallurgy, which could be added in stabilized form in the scrap basket or disintegrated by injection in the EAF. The good correlation is shown in Figure 1 with data from operational tests of different plants in Europe.

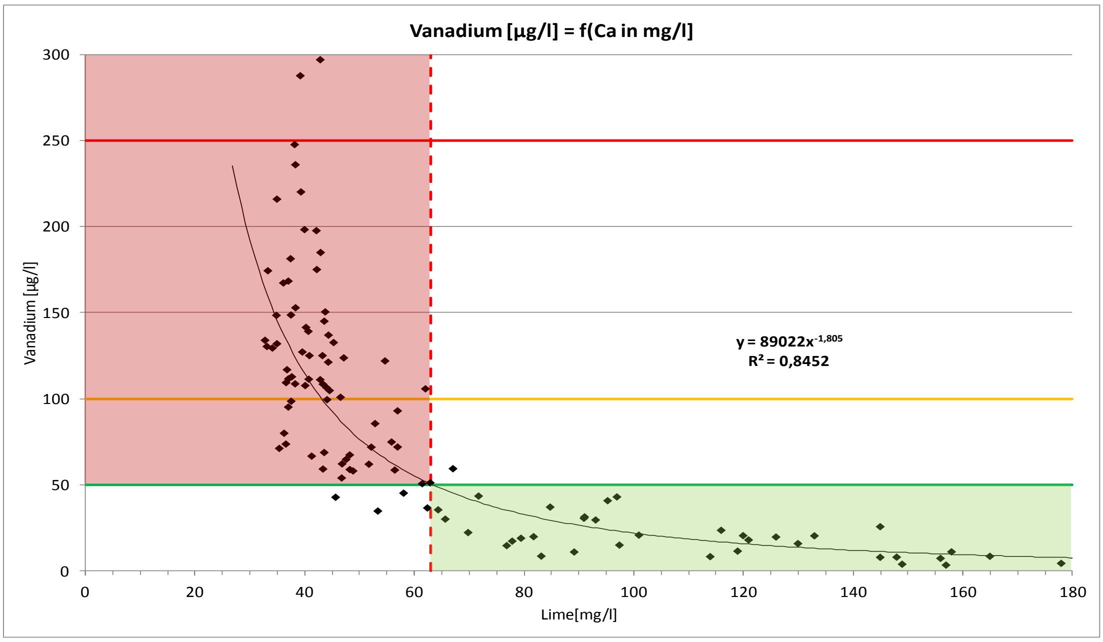

Figure 1: Correlation of vanadium and lime leaching

Another example is leaching of *CHROMIUM*, which is also a regulated parameter in German standards. After long research, bounding of chromium at mineralogical level in spinels was figured out. Compared to lime silicates, spinels are unsolvable in water and leaching of chromium is prevented. “FACTOR CS” was developed by FEhS-institute, which prognoses the chrome leaching of an EAF slag from carbon steelmaking. Operational tests in 11 different electric steel plants in Europe show, how “FACTOR CS” is working, by leaching the slag, based on planned standards, with percolation test (DIN 19528)[3] and shaking test (DIN 19529)[4] with a water/solid ratio of 2:1 (Figure 3).

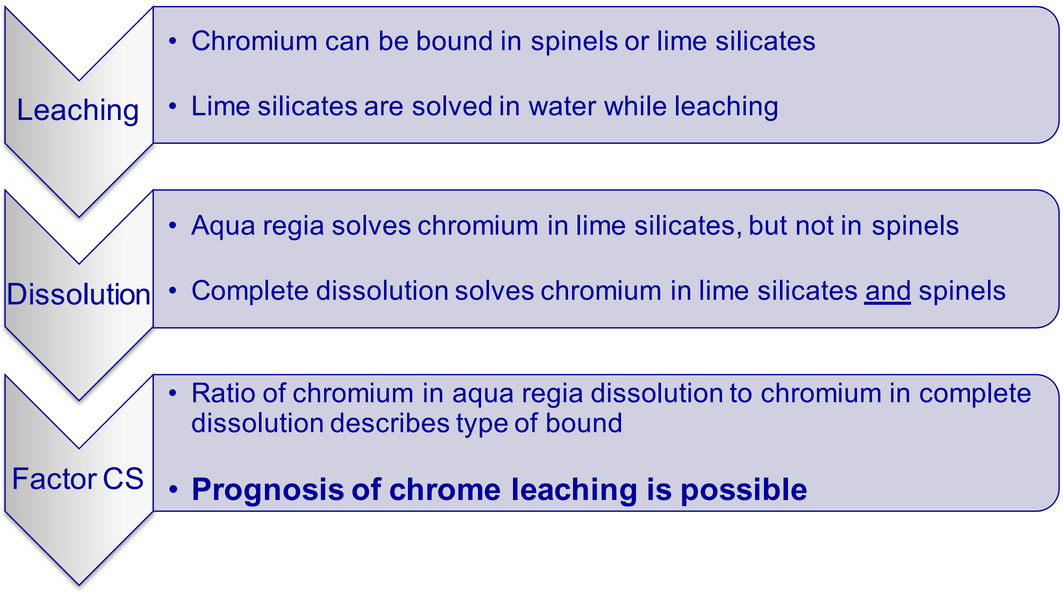

Figure 2: Mechanisms of "FACTOR CS"

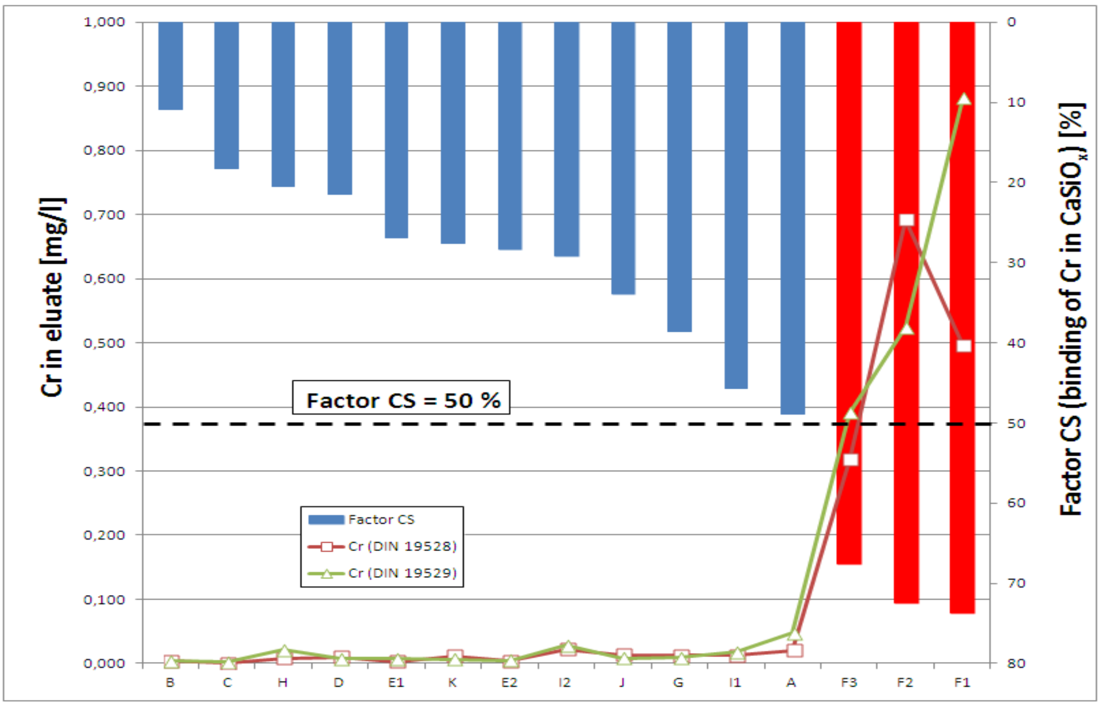

Figure 3: "FACTOR CS" shown on different slags of 11 electric steel plants in Europe

"FACTOR CS" > 50 % shows, that vast bulk of chromium is bound in solvable calcium silicates, as against a low "FACTOR CS" which shows the binding form in unsolvable spinels.

Chrome leaching can be influenced by building spinels which in turn can be forced by adding alumina to the melt. This was also shown in laboratory and operational tests of the FEhS-institute. It is very important that correct dose of components are added, because otherwise leaching of vanadium could be increased; compare Figure 1.

Table 1: Conditioning methods of EAF slag and effects to leaching

		original state	adding alumina	adding alumina + lime	defined dose of alumina + lime
Adding	Alumina		↑	↑	↗
	Lime			↑	↗
Leaching	Chromium	↑	↓	↓	↓
	Vanadium		↑	↓	↓
	electrical conductivity			↑	↓

By adding alumina as well as lime, leaching of chromium and vanadium decreases, but the electrical conductivity will increase when too much lime is added, which is also a regulated parameter.[5] An exact defined dose of both is necessary to get a successful result.

Applications

The marketing of steel slag for a long time was mainly focused on its utilization as a fertilizer (basic slag), disregarding it is to be used within the steel works as a source of lime and iron. In recent decades its use as a building material has gained in significance and currently in Germany approximate 75 % of the EAF slag is used as a building material (Figure 4).

Today there is longtime experience in use of EAF slag in road construction not only in Germany, but all over Europe. The raw material is processed like natural stones in processing plants by crushing and screening to produce aggregates and mixtures conforming to national and European standards.

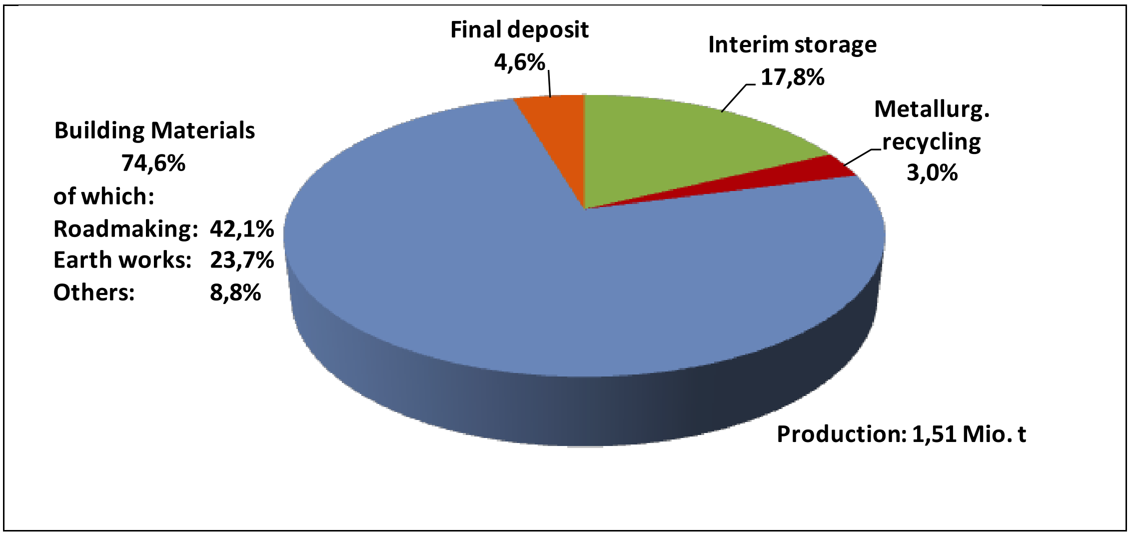

Figure 4: Utilization of EAF slag in Germany, 2013[1]

The main objective of processing is to ensure that the produced aggregates and mixtures will conform to the requirements given in these standards. These mainly include the grain size distribution, strength, shape and resistance to weathering. Concerning steel slag the European aggregate standards cover separate requirements due to volume stability.

Conclusion

Electric arc furnace slag engineering during production, treatment, solidification and processing leads to a quality product which fulfills all current requirements. Due to designated regulations[6] in future, much research work could be necessary to save the high level of utilization of steel slags.

References

1. Th. Merkel "Erhebungen zu Produktion und Einsatz von Hochofen- und Stahlwerksschlacke", *Report des FEhS-Instituts für Baustoff-Forschung e.V.*, **21** (1) 18 (2014).
2. S. Esfahani, M. Barati "Current status of heat recovery from granulated slag", in *Proceedings of 3rd International Symposium on High-Temperature Metallurgical Processing*, 2012.
3. DIN 19528: Elution von Feststoffen — Perkolationsverfahren zur gemeinsamen Untersuchung des Elutionsverhaltens von anorganischen und organischen Stoffen, 2009-1.
4. DIN 19529: Elution von Feststoffen - Schüttelverfahren zur Untersuchung des Elutionsverhaltens von anorganischen Stoffen mit einem Wasser/Feststoff-Verhältnis von 2 l/kg, 2009-1.
5. Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Lieferbedingungen für Gesteinskörnungen im Straßenbau (TL Gestein-StB) Edition 2004/Version 2007.

6. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Verordnung über Anforderungen an den Einbau von mineralischen Ersatzbaustoffen in technische Bauwerke (Ersatzbaustoffverordnung), draft: 31.10.2012.