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INTERNATIONAL CHROMIUM DEVELOPMENT ASSOCIATION

SCIENTIFIC AND ENVIRONMENTAL BACKGROUND FOR THE USE OF FERROCHROME SLAG IN ROAD CONSTRUCTION

FERROCHROME SLAG SUSTAINABLE AND SAFE CONSTRUCTION MATERIAL FOR ROADS

2017

INTERNATIONAL CHROMIUM DEVELOPMENT ASSOCIATION (ICDA)

The International Chromium Development Association (ICDA), established in 1984 is a neutral not-for-profit entity aiming at promoting best practices and a sustainable chrome industry as well as encouraging and developing chromium applications.

Its Members include the vast majority of the world's producers of chromite ore and many users of chromite, including producers of ferrochrome, stainless steel, chromium metal, chromium chemicals, refractory bricks and foundry sands, trading companies, end-users and service providers. The ICDA is a forum for any organization involved with the world of chromium.

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SPECIAL THANKS:

Data collected for this report is anonymous and it is therefore not possible to relate companies to sample since no names nor countries are related to the sample codes, therefore we have the possibility to warmly thank the companies who took part in this report: Albchrome, Eti Krom, FACOR, Glencore, Hernic Ferrochrome, Kazchrome, Mintal, Outokumpu and Vargön Alloys.

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I. FOREWORD

▷ Environmental Properties and Use of Ferrochrome Slag

The slag is essential material in metal production. Mineral materials are added to the metallurgical melting process to create slag which has many important roles during the molten metal process.

The ferrochrome industry currently generates about 13,2 Mt of slag annually. In some countries, ferrochrome slag has been used as construction material for several decades, but in others the material is deposited as waste or non-used by-material. Use of ferrochrome slag in road constructions compensates for natural materials and may improve the resistance to extreme conditions, such as wearing, high temperature, frost and icing.

Circular economy demands are increasing in our societies. Therefore and within the framework of ICDA HSE Committees, a general interest has been expressed to create an independent scientific report on ferrochrome slag properties in relation to safe use of the material.

At the same time, we as ICDA did not have a clear view about challenges or factors that are hindering the use of slag in different countries.

Therefore, the aim of this publication is to

- Compare environmental properties of ferrochrome samples sent by volunteer ICDA member companies to one of the strictest environmental standard used for by-products and similar materials in Europe (independent scientific study, pages 6 to 19).
- Summarize the status in ferrochrome slag use for the main production countries, and finally,
- Encourage ICDA members to use by-product such as ferrochrome slag and when needed to create fruitful and science-based dialogue with national authorities about the possible hinders in the use of slag.

We believe that the scientific evidence about ferrochrome slag being a sustainable material and used as per strict standards would be a good example of the future and resource efficient society.

On the basis of volunteer companies part of the ICDA Membership and representing key geographic area for ferrochrome production (Albania, China, Finland, India, Kazakhstan, South Africa, Sweden, Turkey), ferrochrome slag samples have been collected and tested according to EU legislation for inert waste material which is used also to test the environmental properties and acceptance of by-products in Europe.

These tests have been conducted by recognised professional, independent and accredited laboratory Envitop, based in Finland. Whilst it is clear that legislation vary from a country/geographic area to another, the benchmark was set according to EU legislation as it is recognised as one of the strictest and is currently implemented.

This publication is meant to be a useful support for companies looking to find suitable use solution for their ferrochrome slag, knowledge and scientific facts resulting from it could be used by companies established in countries where local authorities need information to legislate on this critical issue for our industry.

Individual detailed reports are stored for further uses by ICDA as per confidentiality policy. Independent scientific work including analyses and reporting (pages 6 to 19) has been conducted by Sandra van der Veen, Environmental Engineer, Envitop and validated by Dr Jukka Palko, Envitop.

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II. LEACHING BEHAVIOUR OF FERROCHROME SLAGS

AN INVESTIGATION CONDUCTED BY ENVITOP

Sandra van der Veen (MEng) and Jukka Palko (Ph.D)

▷ 1. Purpose

Ferrochrome slag is a by-product from the production of ferrochrome (FeCr), the latter being an essential component for making stainless steel, without chrome there is no stainless steel. The ferrochrome slag is made during the smelting of chrome ore at high temperatures. Chrome ores are smelted typically in electric AC submerged arc furnaces (open, semi-closed or closed) with reductants (coke) and slag formers (e.g. quartzite). Ferrochrome slag is separated from the molten metal product, removed from the furnace and cooled in to the form of stony material.

Slag material, not only ferrochrome slag, is commonly used in many countries as road and house building material, in drainage systems or utilized for the production of cements, concretes, asphalt and refractory bricks. Several slags are registered as chemical substances in the European Inventory of Existing Chemical Substances (EINECS) and as products under the European REACH regulation.

The purpose of this project was to analyse environmental properties (chemical leaching) of ferrochrome slag from all major ferrochrome producing countries and review the legal status of ferrochrome slag in main producing countries ; the chemical stability proving safe use of the material. The research is done by investigating and comparing the leaching behaviour of different kinds of ferrochrome slag. The 15 samples are originated from ferrochrome production plants throughout the world from the most representative countries for the ferrochrome industry.

Typically industrial by-products do not have own environmental standards like leaching limit values. Therefore in many countries the environmental validation of these materials is done by comparing leaching analyses to existing waste criteria.

In this project the results are compared against the European leaching limit values for granular inert waste (European Union Council Decision annex 2003/33/EC) [Reference 1]. Inert materials are chemically stable and do not undergo any significant physical, chemical or biological transformations and may therefore be safely used as by-product or recycled material.

▷ 2. Background

Ferrochrome is a chrome and iron alloy. The vast majority is produced from low-grade ores, known as charge chrome. Charge chrome is generally available in two chromium ranges: 50 - 55% and 63 - 67%, with a carbon content of typically 5 - 12%. Alternatively, high-carbon ferrochrome (HCFeCr) is produced from high-grade lumpy chromite, with a chromium content of about 60 - 70% and 6 - 10% carbon.

Nearly 95% of the total production of ferrochrome is HCFeCr or charge chrome. Over 75% of HCFeCr/charge chrome produced is utilised in the production of stainless steel. (ICDA 2015) [Reference 2].

Refining methods such as argon-oxygen decarburization (AOD) and vacuum-oxygen decarburization (VOD) processes are used to lower the carbon content of stainless melts without excessive oxidation and losses of chromium. Low-carbon ferrochrome (max. 0.25% carbon) and the remainder of HCFeCr are used in applications such as constructional alloy steels, tool steels, superalloys and other specialty metals. LCFeCr is also used to correct chrome percentages during steel production, without causing undesirable variations in the carbon or trace element percentage.

To produce ferrochrome, chromite and magnesiochromite ores ($FeCr_2O_4$, $(Fe,Mg)Cr_2O_4$, $(Mg,Fe)Cr_2O_4$ and $MgCr_2O_4$) are smelted typically in electric AC submerged arc furnaces with reductants (as coke, coal), slag formers (e.g. quartzite, lime stone) and other additives. The heat needed for melting is created by the electric arc formed between the tips of the electrodes in the bottom of the furnace and the furnace hearth. Submerged arc furnaces can be open, semi-closed or closed with correspondingly better thermal, energy and environmental efficiency. According Holappa & Xiao (2004) [Reference 3] chromium loss to slag from an open furnace is significant for runs of several hours at 1500 to 1700 °C. For a closed furnace under similar conditions the loss is considered to be negligible.

Formed slag is separated from the liquid ferrochrome, tapped into ladles and cooled for further processing. The slag cooling is done typically in the open air but also water cooling methods are applicable. The chromium content of the slag is typically 5 to 10%, of which a significant part is as metallic particles dispersed in the slag (Holappa & Xiao 2004) [Reference 3]. If the recovery of chromium metal from the slag is needed, the material could be crushed, fractionated and magnetically separated. Then ferrous metal from slag (MFS) is returned to the furnace for refining and leftover stony slag is removed from the process as waste or reused as an industrial by-product in other applications.

FeCr slags are Al_2O_3-MgO-SiO_2 based with minor contents of calcium oxide (CaO), chromium oxides (CrO_x) and iron oxides (Fe_2O_3). The oxidation state of chromium depends on the ambient oxygen partial pressure and the temperature in the process. Under reducing conditions, divalent (Cr^{2+}) and trivalent chromium (Cr^{3+}) co-exist in the slag. At low temperatures chromium exists as stable trivalent oxides (Cr_2O_3). The fraction of divalent chromium increases with increasing temperature, lowering oxygen potential and decreasing slag basicity. Lower valent oxides (CrO and $CrO_{1.5}$) are only stable at high temperatures (>1650 °C).

When cooling down, CrO disproportions to metallic (Cr0) and trivalent chromium (Cr_2O_3). Oxides with a higher oxidation state (Cr^{6+}) can form under high oxygen partial pressure (Holappa & Xiao 2004) [Reference 3].

In addition, components in ferrochrome slag may occur in different mineral phases which may also effect on environmental properties of slag. The mineralogy was not in the scope of this study. However, it is shown earlier that some inert mineral phases seem to explain the low chemical leaching of metals from ferrochrome slag (Makkonen & Tanskanen 2005) [Reference 4].

Ferrous slags are considered as UVCB substances (Substances of Unknown or Variable composition, Complex reaction or Biological materials). These substances cannot be sufficiently identified by their chemical composition. For UVCB substances, further identifiers have to be considered, such as sources of origin, type of production processes and the ratio of iron, chromium, carbon and other elements. For confidential reasons this summary report does not include detailed information about the sources of origin; only the type of production process (furnace type and temperature range) is given. To identify the different ferrochrome slags, the total elemental concentration is analysed.

Slag material, not only ferrochrome slag, is commonly used in many countries as road and house building material, in drainage systems or utilized for the production of cements, concretes, asphalt and refractory bricks. Several slags are registered as chemical substances in the European Inventory of Existing Chemical Substances (EINECS) and as products under the European REACH regulation.

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Typically industrial by-products do not have own environmental standards like leaching limit values. Therefore in many countries the environmental validation of these materials is done by comparing leaching analyses to existing waste criteria.

In this project the results are compared against the European leaching limit values for granular inert waste (European Union Council Decision annex 2003/33/EC) [Reference 1]. Inert materials are chemically stable and do not undergo any significant physical, chemical or biological transformations and may therefore be safely used as by-product or recycled material.

▷ 3. Test material and sample preparation

Guidelines for sampling and shipping materials were circulated to ICDA Members producing ferrochrome. Sampling was carried out by experienced environmental sampling professionals on-site and according to ICDA instructions. Samples may be crushed before delivery, but according standard method CEN/TS 14405:2004 [Reference 5], on no account shall the material be finely grounded. Subsamples were combined on-site or afterwards in the laboratory by equal weight.

Test samples and their sampling data were collected at Envitop laboratory located in Finland, specialised in environmental research and product development. Leaching tests were performed by authorised and registered laboratory Ahma Environment Ltd. Laboratories (EN ISO/IEC 17025 :2005 FINAS) located in Finland. Test data were collected and reported by Envitop.

The first set of samples (11) was received in the laboratory of Envitop in 2015 and the second batch of samples (4) in 2016 and therefore also tested in two batches. One of the samples (H) was excluded from the study, because the sample did not fulfill the standard criteria (it was grinded to dust <0.15 mm prior delivering to the laboratory). To exclude company names due to confidentiality, samples were labelled using letters (A, B, C, D...). Same letters with numbers were used for the same company when double samples or samples from different production site were included (A-1, A-2, etc...).

The particle size of sample was checked by 4, 8 and 10 mm sieves prior testing. If more than 5% of the sample had a particle size over 10 mm, the oversized fraction was crushed in an accredited laboratory (EN ISO/IEC 17025) and mixed with the rest of the sample prior testing. Information about the slag samples is listed in table 1.

Table 1. Slag sample information

Sample ID	Submerged arc furnace type	Temperature range during production process (°C)	Total sample amount delivered to laboratory (kg)	Amount of subsamples delivered to laboratory (n)	Subsample size (kg)	<4mm (%)	4-8 mm (%)	>8mm (%)
A-1	open, AC	1750	10.0	1	10.0	0.2	3	97
A-2-2015	closed, AC	1750	9.9	1	9.9	78	18	2
A-2-2016	closed, AC	1750	2.5	1	2.5	100	0	0
B	open and semi-closed, AC	1650-1750	2.1	4	0.5	>95	<5	0
C	semi-closed, AC	1650-1750	10.1	1	10.1	41	43	16[2]
D-1	closed, AC	1500-1700	8.1	1	8.1	93	5	3
D-2	closed, AC	1500-1700	12.5	1	12.5	0	4	96[3]
E-1	semi-closed, AC	1600-2000	2.8	5	0.55	100	0	0
E-2-2015	open, AC	1600-2000	2.8	5	0.56	100	0	0
E-2-2016	open, AC	1600-2000	1.7	5	0.33	96	4	0
F-1	closed, AC	1650-1700	8.6	1	8.6	100	0	0
F-2	closed, AC	1650-1700	10.2	1	10.2	42	20	38[1]
G	closed, AC	1800-2000	23.8	5	2.0	13	26	62[1]
* H	open, AC	1750	-	-	-	-		-
I	semi-closed, AC	1650-1830	12.4	1	12.4	0	<5	>95[1]

1 oversized fraction is crushed below 10 mm
2 maximal particle size was 10 mm, no crushing
3 maximal particle size was 11 mm, no crushing
* Sample H did not fulfill the standard test criteria due to finely grounded particle size

▷ 4. Test methods

4.1 - Total elemental analyses

To identify the type of FeCr slag, a partial sample (0.5 kg) was dried and grinded below 75 µm. The pre-treated sample was diluted in lithium borates, a mixture of meta and tetra borates (49.75%/49.75%/1% LiBr) with oxidizing agent NH4NO3 and LiBr to remove surface tensions. The prepared glassy melt was analysed by Fluorescent X-ray spectroscopy (WD-XRF / Claisse M4, Panalytical Magix Fast) for the elements Si, Fe, Al, P, K, Mg, Ca, Cr, Mn, Ti, V. Carbon and sulphur were measured by a combustion gas analyzer. The measurement precision is 0.1%, and for C, S and P 0.01%. The analysis was performed in a highly experienced R&D laboratory. The method is not accredited but particularly applicable for hard, inert or Cr containing minerals.

4.2 - Percolation test CEN/TS 14405

The up-flow percolation test was performed in an accredited Finnish laboratory (EN ISO/IEC 17025) by standard method CEN/TS 14405 [Reference 5]. Seven eluates (marked as F1 - F7) were collected at liquid/dry solid ratios of 0.1 l/kg; 0.2 l/kg; 0.5 l/kg; 1.0 l/kg; 2.0 l/kg; 5.0 l/kg and 10.0 l/kg. After collection the samples were measured for pH and electrical conductivity and filtered. The filtrates (<0.45 µm) were analyzed by ICP-MS (SFS-EN ISO 17294-2:05) and ICP-OES (SFS-EN ISO 11885:2009) for soluble elements (Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, Zn, Hg, U, Ca, k, Mg, Na, S, P and Si). Sulphate, chloride and fluoride were analyzed by ion chromatography (SFS-EN 10304-2).

The test results are compared against the European Landfill Directive leaching limit values for granular inert waste (European Union Council Decision annex 2003/33/EC) [Reference 1], which are widely used for the testing of industrial by-products in the EU.

▷ 5. Results

5.1 - Total elemental concentration

The total elemental concentrations of all the valid FeCr slag samples (14 samples from 12 different FeCr productions plants) tested during this project (2015 - 2016) are presented in table 2. The main elements in the ferrochrome slag samples were magnesium (12 - 27%), silica (12 - 21%) and aluminium (7 - 19%), followed by chromium (2.4 - 9.6%), iron (0.3 - 4.5%), calcium (0.4 - 5.0%) and carbon (<0.1 - 1.3%). Other minor contents (0.01 - 0.5%) were titanium, potassium, sulphur, manganese and phosphorous. The analysed amounts of vanadium, molybdenum and nickel were below or equal to their detection limits (table 1). According the leaching tests (table 2), the slag samples contained also other trace elements such as barium and arsenic (in 2015), but these elements were not analysed by the XRF method used.

The limit value for total organic carbon (TOC) content in inert waste is 3% (EU Council Decision annex 2003/33/E) [Reference 1]. The total carbon (TC) content of the ferrochrome slag samples was <0.1% to 1.3% (table 2). Total carbon is the sum of TOC and TIC (total inorganic carbon). Carbon in FeCr slag exists likely as inorganic carbon (TIC) due to the high temperatures (>1500 °C) in the smelting process which burns the organic matter.

Table 2. FeCr slag type identification by WD-XRF, C and S by gas combustion analyzer, measured as elemental concentrations. Slag samples taken in 2016 are marked bold

	A-1 2015	A2- 2015	A2- 2016	B 2015	C 2015	D-1 2015	D-2 2015	E-1 2015	E-2 2015	E-2 2016	F-1 2015	F-2 2015	G 2015	* H 2016	I 2016	AVE-RAGE	ST-DEV
Mg %dw	27.0	26.4	22.2	22.7	20.1	14.1	13.4	16.9	15.4	15.0	12.9	15.9	11.9	-	12.5	18 ±	5
Si %dw	13.8	15.6	20.9	16.0	13.2	15.1	14.5	12.0	13.6	13.4	14.9	14.4	14.1	-	12.2	15 ±	2
Al %dw	9.8	8.6	6.6	11.7	13.3	14.9	14.4	14.1	12.9	13.0	18.5	15.5	15.0	-	16.7	13 ±	3
Cr %dw	3.1	3.4	2.8	2.4	5.8	7.0	8.4	9.1	9.6	9.0	5.1	4.8	7.5	-	6.1	6 ±	3
Fe %dw	0.6	0.8	0.3	0.6	1.8	3.4	4.0	3.4	2.7	2.8	2.9	2.9	4.5	-	2.7	2 ±	1
Ca %dw	1.1	0.5	0.4	1.3	2.8	1.1	1.1	2.4	3.0	3.1	1.0	2.2	3.3	-	5.0	2 ±	1
C %dw	0.1	0.2	0.2	<0.1	0.3	0.1	1.3	0.6	0.1	0.1	1.3	1.2	1.1	-	0.1	1 ±	1
Ti %dw	0.2	0.2	0.1	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.5	0.3	0.4	-	0.5	0.3 ±	0.1
K %dw	<0.1	0.1	0.3	0.2	<0.1	0.4	0.4	0.2	0.2	0.4	0.2	0.2	0.5	-	0.2	0.3 ±	0.1
S %dw	0.16	0.18	0.18	0.18	0.14	0.18	0.19	0.27	0.31	0.29	0.20	0.23	0.22	-	0.24	0.2 ±	0.1
Mn %dw	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.2	0.1	0.2	0.3	0.1	<0.1	0.1	-	0.1	0.1 ±	0.1
V %dw	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1	-	0.1	<0.1	
Mo %dw	n.a.	n.a.	<0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.1	n.a.	n.a.	n.a.	-	0.1	<0.1	
Ni %dw	n.a	n.a.	<0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	<0.1	n.a.	n.a.	n.a.	-	<0.1	<0.1	
P %dw	0.01	0.01	<0.01	0.02	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.02	0.01	-	<0.01	0.01 ±	0.005

* n.a. = not analyzed
* Sample H did not fulfill the standard test criteria due to finely grounded particle size

5.2 - Leachability (2015-2016)

A summary of the leachability of metals, sulphate, chloride and fluoride from the ferrochrome slag samples tested during 2015-2016 (A1, A-2, B, C, D-1, D-2, E-1, E-2, F-1 F-2, G and I) as well as the limit values for inert, non-hazardous and hazardous waste according EU Council Decision annex 2003/33/EC [Reference 1] are presented in table 3 (page 14).

2015

Chromium, molybdenum (samples B, G, F-2, E-1 and D-2), sulphate (samples G, A-1, F-2 and F-1), chloride (sample F-1), arsenic (samples E-1, G, F-2 and B), sink (sample D-2), vanadium (G, E-1, F-2, F-1) and barium (A-1, F-2, A-2, B, E-2, G, D-2, F-1 and E-1) were the only significant leachable elements from FeCr slag in order of extent; all other tested elements were below detection limits (table 3).

Nine of the eleven tested FeCr slag materials met the European limit values for metal and ion leachability of inert waste; these are slag samples: A-1, C, D-1, D- 2, E-1, E-2, F-1, F-2 and G (table 3). The leachability of chromium from slag samples A-2 and B exceeded the limit value for inert waste; the results were however well below the limit of non-hazardous waste.

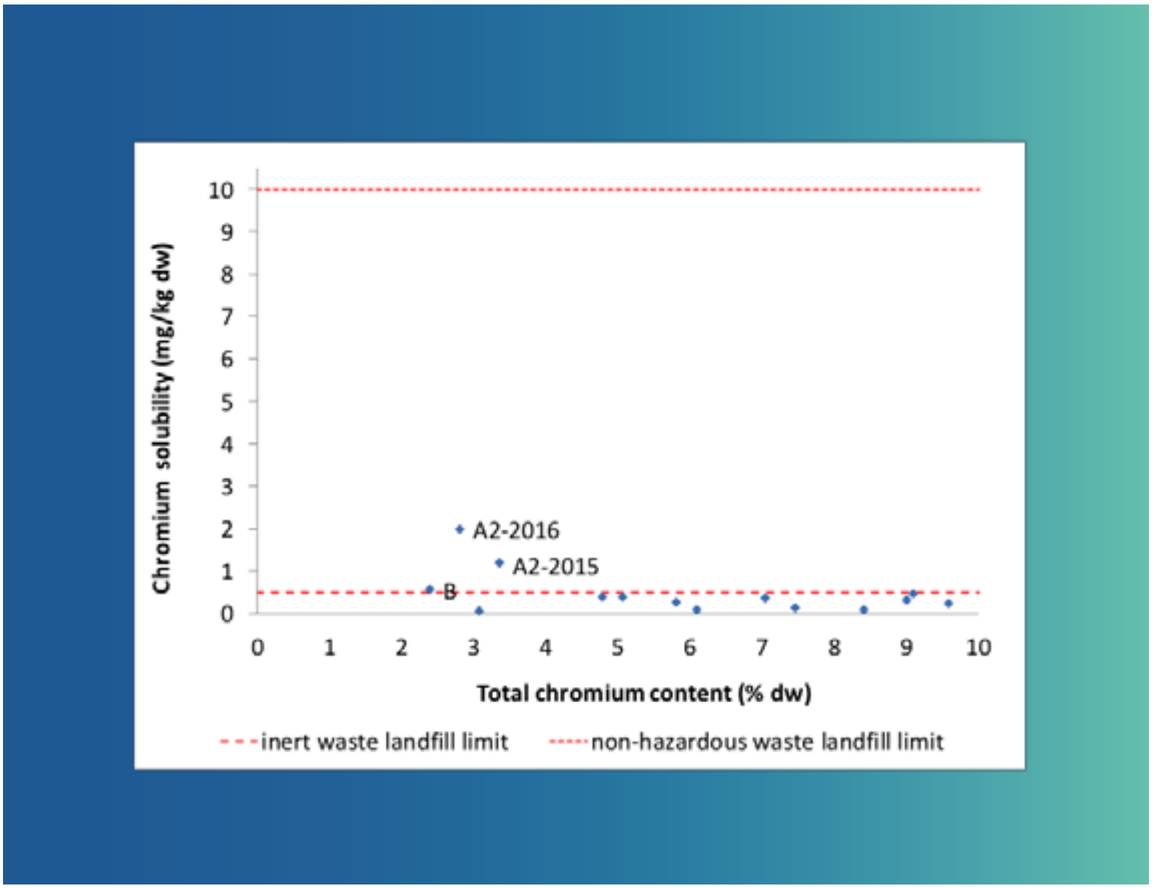
2016

The leachability of chromium from slag sample A-2-2016 (2.0 mg/kg) exceeded the limit value for inert waste (0.5 mg/kg). As in 2015 (1.2 mg/kg), the result was however well below the non-hazardous waste limit (10 mg/kg). The results are shown in table 3 and 5 and picture 1.

The leachability of sample E2-2016 correlated well with the results obtained in 2015 (Envitop Oy, 2.10.2015). The test results of samples E2-2016 and I-2016 met the European limit values for inert waste (table 3).

5.3 - Total chromium content versus chromium leachability (2015-2016)

Picture 1 shows a comparison of the total chromium content of the slag samples tested during 2015 and 2016, and their chromium leachability. The total chromium content of the slag materials fluctuated between 2 and 10 %. The test results show that there is no correlation between high total chromium content and high chromium leachability (table 2, picture 1).



Eleven out of the fourteen tested FeCr slag samples during 2015-2016 met the requirements for inert waste (0.5 mg/kg), even at high total chromium contents. **All samples met the requirements for non-hazardous waste landfills (10 mg/kg)**.

5.4 - pH and conductivity (2015-2016)

The change in pH and electrical conductivity during the percolation test is presented in table 4. For non-hazardous waste the pH should be over 6.0 (EU Council Decision annex 2003/33/EC) [Reference 1]. The landfill directive does not have an upper limit value for pH, neither limit values for the pH of inert waste. The pH of the FeCr slag samples tested in 2016 was between 7.2 and 9.1, which is acceptable (table 4). In 2015 the pH fluctuated between 6.5 and 11.6 (Envitop Oy, 2.10.2015).

The maximum measured electrical conductivity in 2016 was 32 mS/m (sample A2-2016, 1st fraction). The maximum measured value in 2015 was 176 mS/m (Envitop Oy, 2.10.2015). To compare, these values are below the drinking water limit value in Finland, which is 250 mS/m (FINLEX 461/2000) [Reference 6].

Table 3. Summary of the cumulative leachability of metals and ions at a liquid/solid (L/S) ratio of 10 l/kg dw (CEN/ TS 14405 [V]) of FeCr slag samples 2015 -2016. The results are compared to limits set in the European landfill waste directive (European Union Council Decision annex 2003/33/EC) [Reference 1].

Element	Unit	EU LFD Limit Value inert waste	EU LFD Limit Value non hazardous waste	EU LFD Limit Value hazardous waste	A-1 2015	A-2 2015	A-2 2016	B-2015	C-2015	D-1 2015	D-2 2015	E-1 2015	E-2 2015	E-2 2016	F-1 2015	F-2 2015	G-2015	* H-2016	I-2016
		L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10	L/S 10
Arsenic (As)	mg/kg dw	0.5	2	25	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.014	<0.005	0.0057	<0.005	0.0062	0.0078	-	<0.005
Barium (Ba)	mg/kg dw	20	100	300	4.8	0.0084	0.42	0.069	<0.03	<0.03	<0.033	<0.03	0.065	0.057	0.032	0.14	0.036	-	<0.03
Cadmium (Cd)	mg/kg dw	0.004	1	5	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-	<0.002
Chromium (Cr)	mg/kg dw	0.5	10	70	0.071	1.2	2	0.58	0.27	0.37	0.088	0.47	0.25	0.32	0.41	0.39	0.15	-	0.11
Copper (Cu)	mg/kg dw	2	50	100	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	-	<0.015
Iron (Fe)	mg/kg dw	-	-	-	<0.3	<0.3	<0.3	<0.25	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.3	-	<0.25
Mercury (Hg)	mg/kg dw	0.001	0.2	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	-	<0.005
Manganese (Mn)	mg/kg dw	-	-	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02
Molybdenum (Mo)	mg/kg dw	0.5	10	30	<0.005	<0.005	<0.005	0.049	<0.005	<0.005	<0.005	<0.0058	<0.005	<0.005	<0.005	<0.007	<0.013	-	<0.005
Nickel (Ni)	mg/kg dw	0.4	10	40	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01
Lead (Pb)	mg/kg dw	0.5	10	50	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	<0.005
Antimony (Sb)	mg/kg dw	0.06	0.7	5	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	<0.05	<0.05	<0.01	-	<0.01
Selenium (Se)	mg/kg dw	0.1	0.5	7	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.05	<0.05	<0.02	-	<0.02
Tin (Sn)	mg/kg dw	-	-	-	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	<0.005
Vanadium (V)	mg/kg dw	-	-	-	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.050	<0.015	<0.01	0.017	0.022	0.11	-	<0.015
Zinc (Zn)	mg/kg dw	4	50	200	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.077	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	-	<0.05
Chloride (Cl-)	mg/kg dw	800	15000	25000	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	57.2	<50	<50	-	<50
Fluoride (F-)	mg/kg dw	10	150	500	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	<5
Sulphate (SO42-)	mg/kg dw	1000	20000	50000	120	<50	<50	<50	<50	<50	<50	<50	<50	<50	67.6	78.6	140	-	<50

There is no set limit value for vanadium in the European Landfill Directive. The Finnish limit value for inert waste used in building constructions is 2.0 mg/kg (VNa 591/2006).

*Sample H did not fulfill the standard test criteria due to finely grounded particle size

Table 4. Summary of the pH and electrical conductivity (EC) values at liquid/solid (L/S) ratios from 0.1 to 10 l/kg dw (CEN/TS 14405) [Reference 5] of FeCr slag samples, and other percolation test conditions.

Element	Unit	EU LFD Limit Value inert waste	EU LFD Limit Value non ha-zar-dous waste	A-1 2015	A-2 2015	A-2 2016	B-2015	C-2015	D-1 2015	D-2 2015	E-1 2015	E-2 2015	E-2 2016	F-1 2015	F-2 2015	G-2015	* H-2016	I-2016
pH L/S 0.0-0.1 (F1)	-	-	>6.0	10.2	9.1	8.5	7.9	8.8	8.1	7.6	7.4	7.9	8.0	8.1	8.0	11.6	-	7.2
pH L/S 0.1-0.2 (F2)	-	-	>6.0	10.6	9.5	8.3	8.4	7.9	8.5	7.8	7.5	8.0	7.9	7.9	8.1	11.4	-	7.4
pH L/S 0.2-0.5 (F3)	-	-	>6.0	10.4	9.8	8.1	8.0	7.9	8.4	7.9	8.2	8.0	7.8	8.0	8.0	11.3	-	7.5
pH L/S 0.5-1.0 (F4)	-	-	>6.0	10.6	9.8	8.2	8.1	8.4	8.9	7.8	8.1	7.9	7.8	8.7	8.3	10.0	-	7.7
pH L/S 1.0-2.0 (F5)	-	-	>6.0	10.6	9.9	8.0	8.2	8.4	8.1	7.8	7.9	8.0	7.9	9.2	9.2	10.2	-	7.8
pH L/S 2.0-5.0 (F6)	-	-	>6.0	10.0	7.9	8.7	8.0	8.7	9.6	9.0	8.5	8.5	8.3	8.1	8.7	10.1	-	7.8
pH L/S 5.0-10.0 (F7)	-	-	>6.0	10.2	7.9	8.8	7.4	6.5	9.2	8.6	8.5	8.2	9.1	8.1	9.1	9.7	-	7.8
EC L/S 0.0-0.1 (F1)	mS/m	-	-	119	21.8	32.0	19.3	8.2	58.6	8.8	43.7	18.4	24.5	77.0	71.0	176	-	27.2
EC L/S 0.1-0.2 (F2)	mS/m	-	-	92.2	10.8	17.0	13.8	6.2	35.6	7.3	21.8	12.1	16.4	103	25.4	127	-	15.4
EC L/S 0.2-0.5 (F3)	mS/m	-	-	34.3	7.4	11.0	6.9	4.7	14.8	9.3	10.3	7.6	7.6	35.7	14.9	49.1	-	8.8
EC L/S 0.5-1.0 (F4)	mS/m	-	-	17.4	4.9	7.3	4.6	3.8	7.8	4.8	6.9	4.9	5.8	5.8	9.9	13.9	-	4.3
EC L/S 1.0-2.0 (F5)	mS/m	-	-	13.2	3.2	6.1	3.8	3.7	2.8	2.9	6.3	4.3	5.2	4.3	7.7	11.7	-	2.7
EC L/S 2.0-5.0 (F6)	mS/m	-	-	9.3	3.5	6.4	2.3	2.6	1.8	3.9	5.2	2.8	4.9	2.4	4.6	6.8	-	1.9
EC L/S 5.0-10.0 (F7)	mS/m	-	-	9.0	2.2	4.5	2.1	2.2	2.7	1.8	5.1	2.7	4.8	1.5	4.1	5.6	-	1.5
Dry matter	%	-	-	99.9	99.8	100	100	99.7	94.0	98.7	99.9	99.7	100	99.5	99.7	99.9	-	100
Test period				21/07/2015 to 03/09/2015	06/07/2015 to 17/08/2015	21/04/2016 to 27/05/2016	08/06/2015 to 22/07/2015	22/06/2015 to 04/08/2015	05/06/2015 to 02/07/2015	05/06/2015 to 07/07/2015	01/06/2015 to 15/07/2015	08/06/2015 to 21/07/2015	28/09/2016 to 17/10/2016	01/06/2015 to 04/07/2015	01/06/2015 to 16/07/2015	20/07/2015 to 10/08/2015		05/09/2016 to 16/10/2016
<4 mm	%	-	-	0.2	78	100	>95	41	93	0	100	100	100	100	42	13	-	<5
>8 mm	%	-	-	97	2	0	0	16 (8-10 mm)	3	96 (8-11 mm)	0	0	0	0	38	62	-	>95
Crushing of over 10 mm fraction																		
needed	-	-	-	yes	no	no	no	no	no	no	no	no	no	no	yes	yes	-	yes
Diame-ter of test column	cm	-	-	10	10	5	5	10	10	10	5	5	5	10	10	10	-	10
Flow rate	ml/h	-	-	48.5 ± 1.6	50 ± 1.5	14.1 ± 0.8	14.6 ± 0.8	49.8 ± 1.5	49.3 ± 1.5	49.8 ± 1.1	12.6 ± 1.0	12.6 ± 1.0	14 ± 1.5	49.0 ± 0.7	48.4 ± 0.4	49.3 ± 1.2	-	48.7 ± 1.5

*Sample H did not fulfill the standard test criteria due to finely grounded particle size

Table 5. Summary of the cumulative chromium leachability at liquid/solid (L/S) ratios from 0.1 to 10 l/kg dw (CEN/TS 14405) [Reference 5] of FeCr slag samples.

Element	Unit	A-1 2015	A-2 2015	A-2 2016	B-2015	C-2015	D-1 2015	D-2 2015	E-1 2015	E-2 2015	E-2 2016	F-1 2015	F-2 2015	G-2015	* H-2016	I-2016
Cr, L/S 0.1 (F1)	mg/kg dw	<0.0002	0.2	0.46	0.037	0.0093	0.045	0.0025	0.00054	0.00022	<0.0002	0.0034	0.023	0.018	-	0.0023
Cr, L/S 0.2 (F2)	mg/kg dw	<0.0004	0.28	0.69	0.060	0.015	0.069	0.0044	0.0012	0.00022	<0.0004	0.0064	0.036	0.028	-	0.0033
Cr, L/S 0.5 (F3)	mg/kg dw	<0.001	0.43	1.0	0.092	0.025	0.094	0.018	0.011	0.0015	0.0014	0.014	0.062	0.044	-	0.0064
Cr, L/S 1.0 (F4)	mg/kg dw	<0.002	0.54	1.2	0.13	0.038	0.11	0.024	0.027	0.0071	0.0059	0.035	0.098	0.061	-	0.011
Cr, L/S 2.0 (F5)	mg/kg dw	0.0083	0.6	1.4	0.21	0.083	0.13	0.030	0.075	0.029	0.027	0.073	0.14	0.078	-	0.022
Cr, L/S 5.0 (F6)	mg/kg dw	0.023	0.91	1.6	0.36	0.14	0.21	0.060	0.20	0.10	0.14	0.19	0.25	0.11	-	0.060
Cr, L/S 10.0 (F7)	mg/kg dw	0.071	1.2	2.0	0.58	0.27	0.37	0.088	0.47	0.25	0.32	0.41	0.39	0.15	-	0.11
EU LFD limit value		E-1 2015		119	21.8	32.0	19.3	8.2	58.6	8.8	43.7	18.4	24.5	77.0	71.0	176
inert waste	mg/kg dw	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

*Sample H did not fulfill the standard test criteria due to finely grounded particle size

Sample ID	Submerged arc furnace type	<4mm (%)	4-8 mm (%)	>8mm (%)	Total Chromium content (%)	Chromium leachability L/S 10 (mg/kg)	pH (MIN)	pH (MAX)
A-1	open, AC	0.2	3	97	3.1	0.071	10.0	10.6
A-2-2015	closed, AC	78	18	2	3.4	1.2	7.9	9.8
A-2-2016	closed, AC	100	0	0	2.8	2.0	8.0	8.8
B	open and semi-closed, AC	>95	<5	0	2.4	0.58	7.4	8.4
C	semi-closed, AC	41	43	162	5.8	0.27	6.5	8.8
D-1	closed, AC	93	5	3	7.0	0.37	8.1	9.6
D-2	closed, AC	0	4	963	8.4	0.088	7.6	9.0
E-1	semi-closed, AC	100	0	0	9.1	0.47	7.4	8.5
E-2-2015	open, AC	100	0	0	9.6	0.25	7.9	8.5
E-2-2016	open, AC	96	4	0	9.0	0.32	7.8	9.1
F-1	closed, AC	100	0	0	5.1	0.41	7.9	9.2
F-2	closed, AC	42	20	381	4.8	0.39	8.0	9.2
G	closed, AC	13	26	621	7.5	0.15	9.7	11.6
* H	open, AC	-		-	-	-	-	-
I	semi-closed, AC	0	<5	>951	6.1	0.11	7.2	7.8

*Sample H did not fulfill the standard test criteria due to finely grounded particle size

Table 6. Particle size and pH leachability correlation

Sample ID	Submerged arc furnace type	<4mm (%)	4-8 mm (%)	>8mm (%)	Total Chromium content (%)	Chromium leachability L/S 10 (mg/kg)	pH (MIN)	pH (MAX)
A-1	open, AC	0.2	3	97	3.1	0.071	10.0	10.6
A-2-2015	closed, AC	78	18	2	3.4	1.2	7.9	9.8
A-2-2016	closed, AC	100	0	0	2.8	2.0	8.0	8.8
B	open and semi-closed, AC	>95	<5	0	2.4	0.58	7.4	8.4
C	semi-closed, AC	41	43	16[2]	5.8	0.27	6.5	8.8
D-1	closed, AC	93	5	3	7.0	0.37	8.1	9.6
D-2	closed, AC	0	4	96[3]	8.4	0.088	7.6	9.0
E-1	semi-closed, AC	100	0	0	9.1	0.47	7.4	8.5
E-2-2015	open, AC	100	0	0	9.6	0.25	7.9	8.5
E-2-2016	open, AC	96	4	0	9.0	0.32	7.8	9.1
F-1	closed, AC	100	0	0	5.1	0.41	7.9	9.2
F-2	closed, AC	42	20	38[1]	4.8	0.39	8.0	9.2
G	closed, AC	13	26	62[1]	7.5	0.15	9.7	11.6
* H	open, AC	-		-	-	-	-	-
I	semi-closed, AC	0	<5	>95[1]	6.1	0.11	7.2	7.8

[1] oversized fraction is crushed below 10 mm
[2] maximal particle size was 10 mm, no crushing
[3] maximal particle size was 11 mm, no crushing
*Sample H did not fulfill the standard test criteria due to finely grounded particle size

In this research (table 6) there was no clear correlation between ferrochrome slag pH values and chromium leachability. Though it does not mean that there is no correlation between those two.
There is also no correlation found between chromium leachability and arc furnaces types.
It seems that a correlation exists between particle size and chromium leachability. Coarse samples (>95% of the material>8mm), therefore samples A-1, D-2 and I have the lowest chromium leachability. Fine samples have in general higher chromium leachability.

▷ 6. Conclusion

The purpose of this ICDA project was to analyse environmental properties (chemical leaching of metals, sulphate, chloride and fluoride) of ferrochrome slags from major ferrochrome producing countries. Samples were originated from ferrochrome production plants located in Albania, China, Finland, India, Kazakhstan, South Africa, Sweden and Turkey.

FeCr slag samples (11 in 2015 and 3 in 2016) from 12 different factories (A1, A2, B, C, D1/D2, E1, E2, F1/F2, G, I) were tested by an up-flow percolation test (CEN/TS 14405:04) [Reference 5] in an accredited laboratory (EN ISO/IEC 17025). The leachability of metals, sulphate, chloride and fluoride was compared against the European leaching limit values for granular inert waste (European Union Council Decision annex 2003/33/EC) [Reference 1] ; which are widely used for the environmental validation of industrial by-products in the EU. The chemical stability proves safe use of the material.

During this whole study 10 (A1, C, D1, D2, E1, E2, F1, F2, G and I) out of the 12 different tested ferrochrome slag materials met the European limit values for inert waste. For these materials, and End of Waste (EoW) or by-product status for ferrochrome slag material may be obtained promoting use. Chemically stable and inert materials can be safely used as by-product or recycled material for certain applications.

The ferrochrome slag materials of two factories (A2 and B) exceeded the limit value of leachable chromium for inert waste (0.5mg/kg). The leachabilities (0.58 - 2.0mg/kg) were anyhow well below the limit value set for non-hazardous waste landfills (10.0mg/kg). In the European Union, such non-hazardous waste material may be reused in the building constructions of landfill areas for non-hazardous or hazardous waste.

Use of non-hazardous waste may also be acceptable in other applications such as building constructions which are not exposed to large volumes of water. Its environmental acceptability is depending on national environmental regulations or environmental permits for local use.

The test results show that there is no correlation between high total chromium content (Cr total up to 10%) and high chromium leachability. The leachability of slag materials containing up to 10% chromium met the limit value for inert waste. There was also no correlation found between chromium leachability and arc furnaces types nor between chromium leachibility and FeCr slag pH values. There seems to be a correlation between particle size and chromium leachability. Coarse slag samples (>8 mm) had the lowest chromium leachability. It is important to recall that the slag must not be crushed too fine and dust should be minimized.

The results together with another new review [Reference 7] support authorities to define an End of Waste (EoW) or by-product status for slag material in their countries and to encourage safe use of ferrochrome slag. FeCr slag is used in some countries for decades e.g. as road and house building material, in asphalts and refractory bricks. The legal status of ferrochrome slag as a waste does not correlate with the environmental properties of the material.

The waste status in some countries seems to be a heritage from other legislation or depending on local authorities. Risk based approach and knowing environmental properties of material, as showed in this study, is the key element to build circular economy.

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II. STATUS IN USE OF FERROCHROME SLAG IN SOME PRODUCTION COUNTRIES

Based on ICDA HSE Committee member reports in 2017

▷ 1. Finland overview

1.1 - Ferrochrome slag status and use as products

Ferrochrome slag products of Outokumpu in Finland have been used successfully since 1970's for different purposes and it has proven not to cause environmental or health risks. The legal status of ferrochrome slag has been earlier «non-waste» (when by-product definition was not known in national legislation). After publishing European Commission guidelines on by-products, End-of-Waste etc. (2007) under the EU Waste Framework Directive the material has been officially by-product and defined in local environment permit. Because Outokumpu ferrochrome slag is recognised as a by-product its use is not regulated under waste legislation but under construction product and chemical legislation as a REACH registered product. These ferrochrome slag products are quality assured and certified (CE-marked) according to European road construction material standards (EN 13242 and EN 13043) for physical, chemical and technical properties. As construction product ferrochrome slag has a positive economic value and it is sold mainly to construction companies but also to private building purposes. The slag is competing with other mineral construction materials in the market. A part of slag is also sold for refractory production as raw material. Zimbabwe is a flexible country, resources are abundant – labor, energy, chrome ore among others – and with minor investments in logistic infrastructure, furnaces and a great ability to trade material, Chinese firms have done very well over the past years.

EU Decision Tree (2007) under Waste Framework Directive how to define and separate product, by-product and waste [Reference 8]:

T he company has conducted several independent environmental and health risk assessment of its ferrochrome slag. Following assessment conclusions are as examples:

- Occurrence of CrVI (hexavalent chromium) in the Outokumpu ferrochrome slag is very unlikely due to the reductive conditions of the closed ferrochromium furnace process.
- In operating conditions of ferrochrome slag products, hexavalent chromium was barely, if at all, detected. Hexavalent chromium is unstable and in the ground, it will eventually reduce to trivalent form which is generally not harmful.
- There is no danger for animals even if drinking filtered water from slag structures.
- Exposure to metals (Cr, Zn, Ni, Mo etc...) caused by dusting of slag products, direct contact or unintentional swallowing of ferrochrome slag does not produce a significant health risk. Slag products are practically dustless.

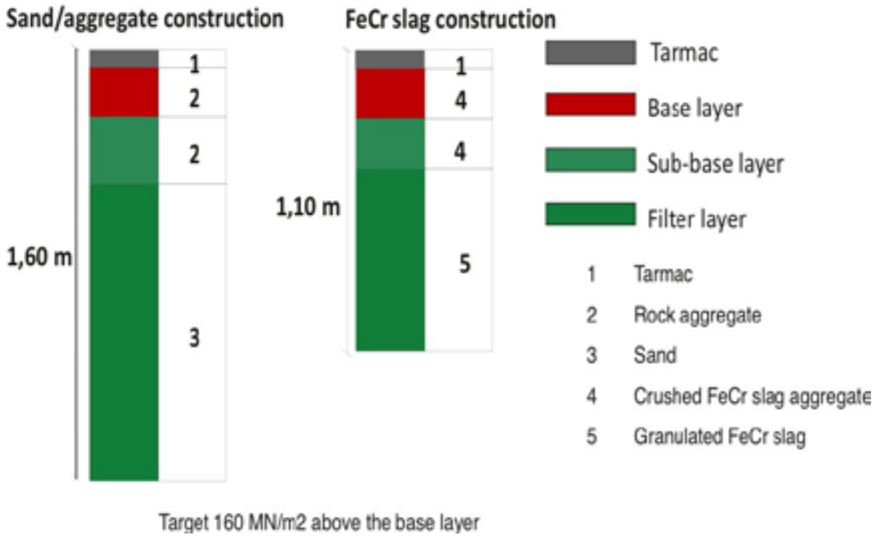
Conclusion from independent environment and health risk analyses is that use of Outokumpu ferrochrome slag products in earth construction will not lead to pollution of environment or health risks even in the longer term.

1.2 - Environmental and economical benefits of Outokumpu ferrochrome slag products

It has been scientifically documented that Outokumpu ferrochrome slag products are chemically very stable and inert due to the slag forming process and mineralogy of slag.

In a northern cold and wet climate where roads are exposed to extreme conditions (ice, frost, cold temperature, wetness), it is necessary to have a technically sustainable material for road building.

Comparison of construction thicknesses in roads: ferrochrome slag products save money and environment



Source: Outokumpu

By using ferrochrome slag products, the road structure can be built thinner than when using natural aggregates due to better physical properties of the ferrochrome slag.

Therefore the use of slag saves money and natural virgin materials, hence contributes to saving environment and resources.

In cold and wet climate road structure has to resist frost and icing, making then ferrochrome slag as the most suitable option.

In Finland, the use of Outokumpu ferrochrome slag amounts to approximately 700 000 tonnes/year, saving over 1000 000 tonnes of virgin material and meaning 350 000 tonnes less CO_2 emissions annually.

Interview with Markkus Kannala, Technical Director, City of Tornio

Since when have you been using ferrochrome slag? Are you satisfied with this product?
City of Tornio has started to use ferrochrome slag since 1980s in its own street construction and renovation projects. We have been very satisfied with the material as well as with the cooperation between Outokumpu company as construction material provider.

What are the benefits of using ferrochrome slag for road construction at both mechanical and environmental levels?
Ferrochrome slag has better geotechnical properties than natural sand which can be replaced by the slag. Its low capillarity added with its insulation properties enable the use of thinner construction layers reaching sufficient protection against the frost which is important in our cold and wet climate. Certainly also an advantage in areas where the bearing of the soil is weak, as in Tornio.
The use of ferrochrome slag saves natural sand resources sustaining groundwater and landscape. Additionally, Outokumpu's ferrochrome plant is situated closely to the urban area of Tornio with its development projects, keeping the transportation distances low.

Would you encourage further use of ferrochrome slag in countries that have this material and need road infrastructure?
Based on our experience the use of ferrochrome slag is highly recommended.
The benefits are undisputed creating a win-win-win situation between the constructor, slag producer and the environment

▷ 2. South Africa overview

2.1 - South Africa ferrochrome slag, a safe aggregate material as per GHS local standard

In 2013, South African ferrochrome producers, with the support of FAPA (Ferro Alloy Producers Association) released a report advocating beneficial use of ferrochrome slag as aggregate material [Reference 9].

Lead consultant for this work were JMA Consulting (Pty) Ltd. providing sustainable environmental solutions through integrated science and engineering and INFOTOX (Pty) Ltd. expert in retrieval and scientific interpretation of ecotoxicological information.

Holding about 75% of world chrome ore reserves located within the Bushveld Igneous Complex, South Africa is a leading ferrochrome producer. South Africa has adopted the Globally Harmonized System (GHS) of classification and labeling of chemicals, as represented in South African National Standard SANS 10234:2008 Ed 1.1.

The aim of the GHS is to have worldwide, the same criteria for classifying chemicals according to their physical, health hazards, environmental hazards and hazard communication requirements for labeling and safety data sheets.

GHS is based on a broad description of hazard classes in the main categories of physical hazards, health hazards and hazards to the aquatic environment. For each of the hazards a series of hazard statement codes (H-codes) has been developed, to assist in the classification.

Physical hazards under GHS refer to explosive properties, flammability, oxidizing properties, self-reacting and self-heating characteristics, and pyrophoric properties, generation of hazardous or flammable gases when in contact with water and chemical properties that will materially damage, or even destroy metals.

According to the FAPA, JMA Consulting and INFOTOX Report **there are no physical hazards associated with the South African ferrochrome slag as defined in the GHS.**

Hazard Class	Classification	Overall Classification of SA ferrochrome Slag
HUMAN HEALTH		
Acute toxicity: Oral	Not classified	Not hazardous with regard to human health, not classified under any human health hazard category applicable to SANS 10234:2008.
Acute toxicity: Inhalation	Not classified	
Acute toxicity: Dermal	Not classified	
Skin corrosive or skin irritant	Not classified	
Respiratory sensitisation and skin sensitisation	Not classified	
Germ cell mutagenicity	Not classified	
Carcinogenicity	Not classified	
Reproductive toxicity	Not classified	
Specific target organ toxicity - single exposure	Not classified	
Specific target organ toxicity - repeated exposure	Not classified	
AQUATIC ECOSYSTEMS		
Acute hazards	Not classified	Not hazardous with regard to the aquatic environment, not classified under any environ-mental hazard category appli-cable to SANS 10234:2008.
Chronic hazards	Not classified	

In addition to GHS compliance tests, further assessment have been performed:

- **pH dependence of leaching characteristics of ferrochrome slag**

Results of the pH tests on leaching characteristics of the ferrochrome slag confirmed that changes in pH may affect the leaching potential of certain elements. It would be safe to use the slag under conditions of its natural pH or higher.

- **Generic assessment of exposure to dust from ferrochrome slag.**

It was concluded that use scenarios of ferrochrome slag that have a potential to generate dust would have insignificant effects on human health in communities if dust levels are managed within the South African ambient air quality standard for PM10.
Similarly, it was demonstrated that occupational exposure to dust during typical dust generating scenarios would not exceed occupational exposure limits for hazardous elements when dust is controlled within the occupational exposure limit for respirable dust.

There would thus be insignificant occupational health risks associated with ferrochrome slag in typical use scenarios (Van Niekerk 2011).

2.2 - Classification of South African ferrochrome slag for landfill disposal

The definition of «inert material» in the South African Waste Act means a material that:

- does not undergo any significant physical, chemical or biological transformation after disposal;
- does not burn, react physically or chemically biodegrade or otherwise adversely affect any other matter or environment with which it may come into contact; and
- does not impact negatively on the environment, because of its pollutant content and because the toxicity of its leachate is insignificant.

The South African ferrochrome slag thus classifies as inert, according to the definition of inert waste in the Waste Act (Van Niekerk 2011).

2.3 - Ferrochrome slag: creating employment and saving primary resources for South Africa

For the same reasons as mentioned in the example of Finland, the use of ferrochrome slag in South Africa, a country that has more than 500 registered companies in the sand and aggregate sector, would be a sustainable way to recycle an inert material saving them primary resources.

The beneficial use of ferrochrome slag can potentially create many jobs in civil construction projects as various uses exist and ferrochrome slag treatment to transform it into an aggregate material can also generate a area for employment in our industry.

According to South Africa calculation, 1 job per 1000 tonnes of slag can be created, with an average of 5 000 000 tonnes of slag produced annually in South Africa, it means a potential creation of 5000 jobs [Reference 10].

III. SUMMARY OF LEGAL STATUS OF FERROCHROME SLAG INCLUDING OTHER PRODUCING COUNTRIES IN 2017

ALBANIA:

Ferrochrome slag is classified as waste product. Albania major ferrochrome producer is disposing ferrochrome slag to landfill though currently studying new way of using it having in consideration refractory properties.

China: not reported legal or centralized instructions. The use rate of FeCr slag in e.g. road construction is high in some provinces, but low in some others.

FINLAND:

Ferrochrome slag was earlier «non-waste», now by-product. By-product is regulated under construction product and chemical legislation as a REACH registered product.

INDIA:

Legal base unclear. Recommended to conduct regular test as for any material that are used in contact with natural soils. Use of slag is rare and no country wide specific decision exists.

KAZAKHSTAN:

regulated by the rules for the design and construction of roads. Standard requirements do not apply to slag gravel, sand and ready-mix concrete used for the preparation of mineral-based and other types of binders.

SOUTH AFRICA:

classified as inert material according to the definition of inert waste in the Waste Act. The use of slag is in practice very limited due to «forever lasting» legal ownership of the waste material (material is hard to sell).

SWEDEN:

The tendency of environment authorities has been to define metal industry slag as waste. This is also in the case of ferrochrome slag.

TURKEY:

The regulation on the general principles of waste management is applied, ferrochrome slag is classified as «other slag except for the non-ferrous thermal metallurgy» under the 10 08 09 waste code in the general waste list. It is also classified as non-hazardous waste.

The legal status of ferrochrome slag in different countries does not correlate with the environmental properties of the material. The waste status in some countries may be a heritage from other legislation or depending on local authorities.

Risk based approach and knowing environmental properties of material, as showed in this publication, is the key element to build the circular economy and sustainability.

The results from the leaching study of this publication support authorities and companies to define the ferrochrome slag as End of Waste (EoW) or By-Product material, also to encourage use ferrochrome slag safely in certain applications.

As shown, ferrochrome slag is used in some countries for decades e.g. as road and house building material, in asphalts and refractory bricks without any evidence of risks.

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▷ APPENDIX

APPENDIX: ICDA. Guidelines for ferrochrome slag testing. Sample preparation and shipment. 2015

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