TECHNIKA OCHRANY PROSTREDIA

TOP 2019

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Steelmaking slags – prospective source of secondary metals

Tomáš Havlik

Ústav recyklačných technológií

FMMR TUKE

CHROMIC

INSTITUTE OF RECYCLING TECHNOLOGIES Technical University of Kosice

AGENTÚRA NA PODPORU VÝSKUMU A VÝVOJA

Rozdelenie ocelí

<table>
<tr><th>Trieda ocele</th><th colspan="3">Druh ocele podľa chemického zloženia</th></tr>
<tr><td>10</td><td colspan="2" rowspan="2">Konštrukčné ocele obvyklých akostí (chemické zloženie sa spravidla neudáva a nezaručuje)</td><td>Obsah fosforu a síry v hotovom výrobku sa nezaručuje; zaručuje sa iba v skúšobnej vzorke pri oceliach 10 400 a 10 451</td></tr>
<tr><td>11</td><td>Obsah fosforu a síry sa zaručuje v hotovom výrobku, príp. v skúšobnej vzorke</td></tr>
<tr><td>12</td><td rowspan="6">Konštrukčné ocele ušľachtilé (chemické zloženie sa zaručuje v hotovom výrobku)</td><td>uhlíkové</td><td>na cementovanie
na zušľachťovanie
pružinové</td></tr>
<tr><td>13</td><td rowspan="4">zliatinové:
na cementovanie
na zušľachťovanie
na priame kalenie
na nitridovanie
pružinové</td><td>ocele: Mn; Si; Mn - Si</td></tr>
<tr><td>14</td><td>ocele: Cr; Mn - Cr; Si - Cr;
Cr - Al; Cr - Mn - Si</td></tr>
<tr><td>15</td><td>ocele: Cr - Mo; Cr - V; Mn - Cr - Mo;
Mn - Cr - V; Cr - Mo - V;
Cr - Mo - Al</td></tr>
<tr><td>16</td><td>ocele: Ni; Cr - Ni; Cr - Ni - Mo;
Ni - Cr - W</td></tr>
<tr><td>17</td><td>zliatinové s vy-sokým obsahom prísadových prvkov</td><td>ocele: koróziivzdorné
žiaruvzdorné
žiarupevné
fyzikálne a i.</td></tr>
<tr><td>18</td><td colspan="3">Spekané prášky oceľové a liatinové (uhlíkové a zliatinové).
Spekané karbidy.</td></tr>
<tr><td>19</td><td colspan="3">Nástrojové ocele:uhlíkové,
zliatinové,
zliatinové rýchlorezné,
zliatinové na liate nástroje</td></tr>
</table>

Prímesi v oceliach

- ***Prímesi závisia od typu ocele:***
  - Nízkouhlikaté
  - Vysokouhlíkaté
  - Ušľachtilé
  - Špeciálne
  - Ferozliatiny
  - ....

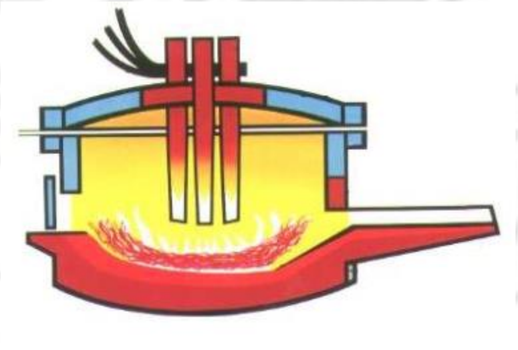
prímesi	
	C
škodlivé	S, O_2, P, N_2, H_2, As, Sb, Pb, Sn, Zn, Cd, Hg, …
zliatinové/prospešné	Mn, Si, Cr, Ni, Mo, V, W, Al, B, Co, Cu, Nb, Ta, ...
PVZ (dezoxidácia)	Ce, lantanoidy,....

Výroba ocele

- ***Principiálne možnosti***
  - Kyslíkový konvertor
  - Bessemerov konvertor
  - Thomasov konvertor
  - AOD konvertor
  - S-M pece
  - Elektrické oblúkové pece
  - iné

Výroba ocele.sk

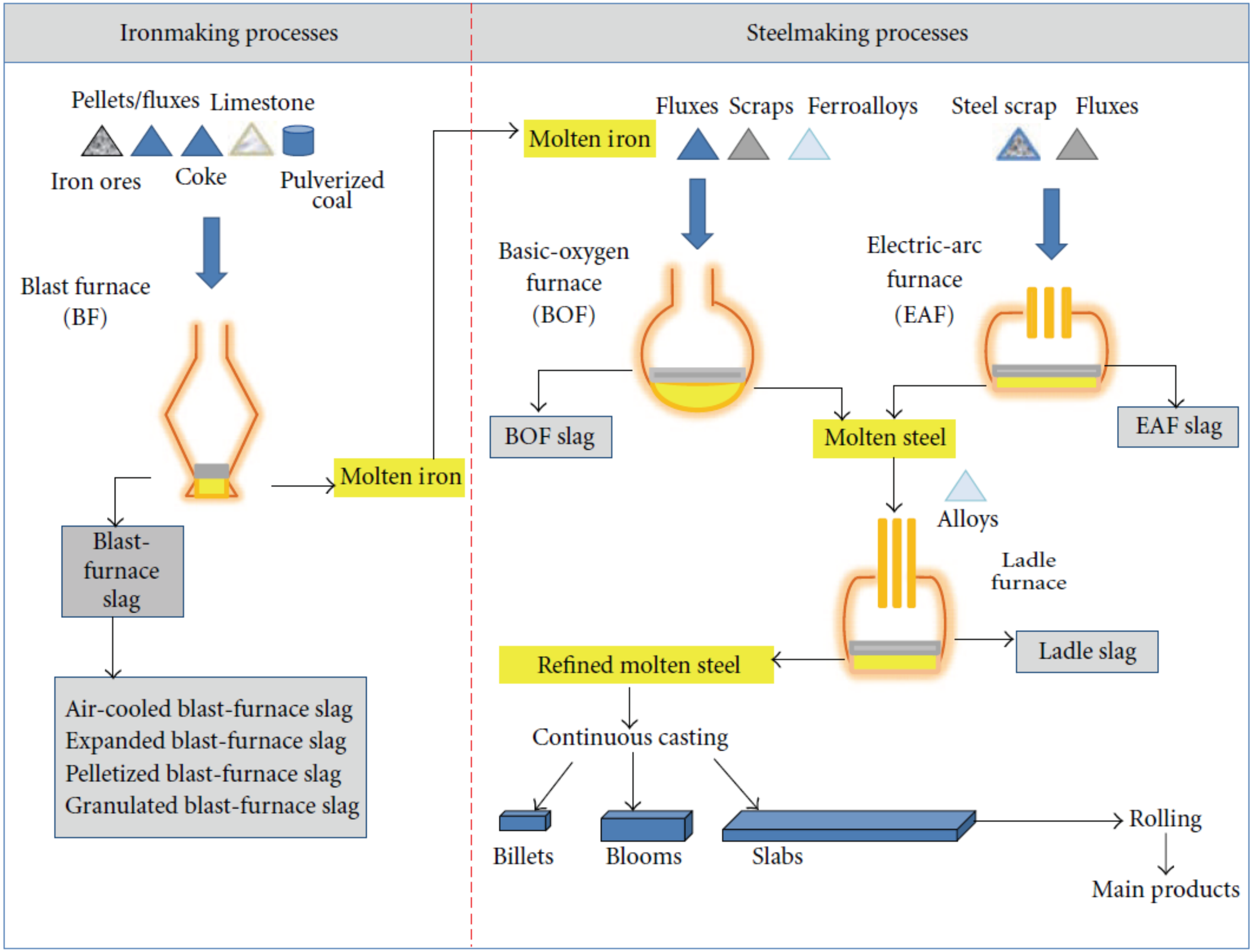
- ***Principiálne možnosti***
  - Kyslíkový konvertor - USSKe
  - Bessemerov konvertor
  - Thomasov konvertor
  - AOD konvertor
  - S-M pece
  - Elektrická oblúková pece – ŽP, SSM
  - iné



Vstupy pre výrobu ocele

- Surové železo
- Šrot
- Troskotvorné prísady (kyslé, zásadité)
- Kyslík
- Dezoxidačné prísady
- Desulfurizačné prísady
- Defosforizačné prísady
- Legúry
- Modifikátory
- ....

Materiálové toky



Vstupy a výstupy BOF konvertor

VSTUP		VÝSTUP	
Suroviny	**kg/t tekuté oceli**	**Produkty*3**	
surové železo*1	820 – 980	Bramy	**1000 kg**
Šrot	170 – 255	Bloky	
železná ruda	7 – 20	Sochory	
ostatní materiál s obsahem železa	7 – 10	Ingoty	
Koks	0,02 – 0,48		
Vápno	30 – 55	**Energie**	**MJ/t tekuté oceli**
Dolomit	1,5 – 4	konvertorový plyn *4	0 – 650 – 840
legury *2	3 – 9	pára * 5	0 – 20 – 270
	m³/t tekuté oceli	**Plynné emise**	**g/t tekuté oceli**
Kyslík	45 – 55	prach	15 – 80
		Cr *6	0,01 – 0,36
		Cu*6	0,01 – 0,04
Energie	MJ/t tekuté oceli	Pb*6	0,13 – 0,9
zemní plyn	20 – 55	Mn*6	< 0,01 – 1,2
Elektřina	38 – 120	NOx	5 – 20
Pára	30 – 140	CO	1500 – 7960
		CO_2*7 kg/t tekuté oceli	11,2 – 140
		PAH *8 mg/t tekuté oceli	0,08 – 0,16
		PCDD/F µg I-TEQ/t to**	< 0,001 – 0,06
	Nm³/t tekuté oceli		
stlačený vzduch	4 – 18		
		odpadní zbytky/ vedlejší produkty	kg/t tekuté oceli
	m³/t tekuté oceli	odsířená struska	2,2 – 19,2
Voda	0,4 – 5	konvertorová struska	85 – 110
		struska ze sekundární metalurgie	2 – 16
		výhoz	4 – 5
		prach	1,5 – 7
		struska z kontinuálního odlévání	4 – 5
		válcovenské okuje	1,2 – 6
		suť	0,8 – 5
			m³/t tekuté oceli
		odpadní voda	?

Vstupy a výstupy EOP

Vstupy			**Výstupy**		
SUROVINY			*PRODUKTY*		
Šrot	kg/t	1080-1130	tekutá ocel (TO)	kg	1000,00
vápno	kg/t	30-80	**EMISE** [3]		
uhlí	kg/t	13-15	prach	g/t	1-780 [4]
grafitové elektrody	kg/t	1,5-4,5	Hg	mg/t	6-4470 [5]
vyzdívka	kg/t	1,9-25,1 (prům. 8,1)	Pb	mg/t	16-3600 [6]
tekutá tavenina [1]	kg/t		Cr	mg/t	8-2500 [7]
DRI [2]	kg/t		Ni	mg/t	1-1400 [8]
surové železo [2]	kg/t		Zn	mg/t	280-45600 [9]
			Cd	mg/t	< 1-72 [10]
			Cu	mg/t	<1-460 [11]
ENERGIE			HF	mg/t	<700-4000 [12]
celková energie	MJ/t	2300-2700	HCl	mg/t	800-9600 [12]
elektřina	MJ/t	1250-1800	SO_2	g/t	24-130 [12]
kyslík	m^3/t	24-47	NOx	g/t	120-240 [13]
			CO	g/t	740-3900 [12]
Voda		uzavřený chladící okruh	TOC	g C/t	16-130 [14]
			benzen	mg/t	170-4400 [12,15]
			chlorbenzeny	mg/t	3-37 [16]
			PAH [17]	mg/t	3,5-71 [18]
			PCB [19]	mg/t	1,5-45 [20]
			PCDD/F	µg I-TEQ/t	0,07-9 [21]
			Pevné odpady/ vedlejší produkty		
			struska z pece	Kg/t	100-150
			struska z pánve	Kg/t	10-30
			prach	Kg/t	10-20
			žáruvzdorné cihly	Kg/t	2-8
			Hluk	DB (A)	90-125

Svetová produkcia trosky / rok

- ***Svetová ročná produkcia ocele:*** 1.5 mld ton
  - 1.2 mld ton primárna BOF
  - 0.3 mld ton druhotná EOP

- ***Svetová produkcia trosky:***
  - 0.12 mld ton primárna výroba
  - 0.04 mld ton druhotná výroba

Troska

- Troska je v zásade zliatina oxidov s možným obsahom mechanických prímesí taveného kovu alebo výmurovky
- Úlohou trosky je oddeliť nežiaduce prímesi z taveniny a chrániť taveninu pred vonkajšími vplyvmi
- Vlastnosti trosky – prídavok troskotvorných prísad

Troska

- Rôzne zariadenia – rôzna troska
- Rôzny vyrábaný kov (= oceľ) – rôzna troska
- Rôzny technologický postup – rôzna troska
- ……

Vplyv vsádzky !

Zloženie trosiek - príklady

Table 1: Chemical composition of BOF, EAF, and Ladle Slags.

		Oxide composition (%)											
Reference	Slag type	CaO	SiO_2	Al_2O_3	MgO	FeO	Fe_2O_3	Fe_{total}	SO_3	MnO	TiO_2	P_2O_5	Free CaO
Das et al. [7]	BOF	47.9	12.2	1.2	0.8	26.3	—	—	0.3	0.3	—	3.3	—
Juckes [8][a]	BOF	36.4–45.8	10.7–15.2	1–3.4	4.1–7.8	—	—	19–24	0.1–0.2	2.7–4.3	—	1–1.5	2.5–12
Mahieux et al. [9]	BOF	47.5	11.8	2.0	6.3	—	22.6	—	—	1.9	0.5	2.7	—
Poh et al. [10]	BOF	52.2	10.8	1.3	5.04	17.2	10.1	—	—	2.5	0.6	1.3	10.2
Shen et al. [11]	BOF	39.3	7.8	0.98	8.56	—	38.06	—	0.0	4.2	0.9	—	—
Shi [12]	BOF	30–55	8–20	1–6	5–15	10–35	—	—	0.1–0.2	2–8	0.4–2	0.2–2	—
Tossavainen et al. [13]	BOF	45.0	11.1	1.9	9.6	10.7	10.9	—	—	3.1	—	—	—
Waligora et al. [14]	BOF	47.7	13.3	3.0	6.4	—	24.4			2.6	0.7	1.5	9.2
Xuequan et al. [15][b]	BOF	45–60	10–15	1–5	3–13	7–20	3–9	—	—	—	—	1–4	—
Barra et al. [16]	EAF	29.5	16.1	7.6	5.0	—	32.56	—	0.6	4.5	0.78	0.6	—
Luxán et al. [17]	EAF	24.4	15.4	12.2	2.9	34.4	—	—	—	5.6	0.56	1.2	—
Manso et al. [18]	EAF	23.9	15.3	7.4	5.1	—	—	42.5	0.1	4.5	—	—	0.5
Shi [12]	EAF	35–60	9–20	2–9	5–15	15–30	—	—	0.1–0.2	3–8	—	0.0–0.3	—
Tossavainen et al. [13]	EAF	38.8	14.1	6.7	3.9	5.6	20.3	—	—	5	—	—	—
Tsakiridis et al. [19]	EAF	35.7	17.5	6.3	6.5	—	26.4	—	—	2.5	0.8	—	—
Nicolae et al. [20]	Ladle	49.6	14.7	25.6	7.9	0.44	0.22	0.17	0.8	0.4	—	0.2	—
Shi [12]	Ladle	30–60	2–35	5–35	1–10	0–15	—	—	0.1–1	0–5.0	—	0.1–0.4	—
Qian et al. [21]	Ladle	49.5	19.59	12.3	7.4	—	0.9	—	—	1.4	—	0.4	2.5
Setién et al. [22]	Ladle	50.5–57.5	12.6–19.8	4.3–18.6	7.5–11.9	—	1.6–3.3	—		0.4–0.5	0.3–0.9	0–0.01	3.5–19
Tossavainen et al. [13]	Ladle	42.5	14.2	22.9	12.6	0.5	1.1	0.4	—	0.2	—	—	—

[a]The range of values are compiled based on the chemical composition data from 4 different sources in Great Britain provided by Juckes [8].
[b]Xuequan et al. [15] report chemical composition of steel slag from refining process (not specified as BOF).
— = data not available.

Zloženie trosiek - príklady

Type of slag	SiO_2	Cr_2O_3	Al_2O_3	CaO	MgO	FeO	Fe_2O_3	Fe	V	Mn	Ti	Source
BOF	9-18	n	0,9-2,8	34-55	2,5-10	n	n	14-30	0,1-3	0,93-6,2	n	[15]
	9,31	0,20	2,20	41,59	8,93	22,4	n	n	0,5-1,22	2,7	1,092	[16]
LD	12-12,6	n	1,22-1,58	47,88-50,0	0,82-1,5	26,3-27,89	1,43-2,79	n	n	0,21	0,1-1,86	[10, 17]
	8,52	n	1,27	41,86	11,15	25,22	n	n	0,84-1,4	3,19	n	[18]
	17,6	0,56	0,52	23,8	5,85	n	n	17,3	1,65	7,1	2,50	[19]
EAF (carbon steel)	31,7	4,7	4.6	47.4	7.0	1,2	n	n	n	n	n	[10]
	25,6	2,00	10,6	31,6	11,9	14,5	n	n	0,028	2,43	0,48	[20]
EAF (high-alloy steel)	8,39	n	1	53,74	n	n	20,95	n	0,27-0,948	7,0	0,76	[21]
	17,6	0,56	0,52	23,8	5,85	n	n	17,3	5,88	7,1	2,50	[12]
Stainless steel	29,3-34,3	1,8-8,8	2,9-7,8	47,3-51,0	4,9-10,8	0,5-2,1	n	n	n	0,54-2,04	0,36-0,42	[22]
	26,5-33,5	2,39-2,84	1,65-10,07	43,27- 54,1	3,65-8,59	n	1,36-1,43	n	n	n	0,13-0,74	[23]
	29,36-40	3,67-4,00	4,13-4,5	36,7-46,6	4,59-5,00	0-9	6,13-6,5	n	n	n	n	[24]
	26,3-31,2	5,51-9,5	1,66-9,7	45,5-47,6	3,65-7,3	n	n	1,75-7,4	n	n	0,13-0,68	[15]
Ferrochrome	1	5	12	36	24	n	11	n	n	n	n	[15]
	26-30	14-16	22-24	2-3	24-26	2-4	n	n	n	n	n	[11]
	25-28	10-17	15-21	n	21-24	2-6	n	n	n	n	n	[25]
	42,10	6,04	5,86	0,95	10,30	3,98	n	n	n	0,26-0,5	0,08	[26]
	25-30	10-15	16-22	3-5	22-25	2-5	n	n	n	n	n	[27]
AOD slag	24,67	0,51	1,07	55,9	5,85	1,15	n	n	0,008	n	0,41	[14]

Zloženie trosiek - príklady

Component		Ladle slag	BOF-slag	EAF-slag 1	EAF-slag 2
Fe_2O_3	%	1.10	10.9	0.98	20.3
FeO	%	0.50	10.7	3.25	5.60
Fe met.	%	0.44	2.3	0.06	0.63
Al_2O_3	%	22.9	1.92	3.72	6.67
CaO	%	42.5	45.0	45.5	38.8
MgO	%	12.6	9.57	5.22	3.94
MnO	%	0.23	3.14	2.01	4.99
SiO_2	%	14.2	12.1	32.2	14.1
Cr	mg/kg	2700	480	32700	26800
Mo	mg/kg	280	50	500	70
Zn	mg/kg	370	50	130	260
Ni	mg/kg	70	25	3180	90
Cu	mg/kg	20	8	140	160
K	mg/kg	80	220	590	<20
Na	mg/kg	<20	<10	150	<20
P	mg/kg	<50	2270	<50	2000
Ti	mg/kg	840	8270	7910	2400
V	mg/kg	280	14800	310	1700
M_b		1.5	3.9	1.4	2.1

Zloženie trosiek - príklady

Table 2 Typical compositions of iron/steel slag [1)]

	Blast furnace slag	BOF slag	EAF slag		Reference	
			Oxidation slag	Reduction slag	OPC *	Andesite
CaO	41.7	45.8	22.8	55.1	64.2	5.8
SiO_2	33.8	11.0	12.1	18.8	22	59.6
T-Fe	0.4	17.4	29.5	0.3	3.0	3.1
MgO	7.4	6.5	4.8	7.3	1.5	2.8
Al_2O_3	13.4	1.9	6.8	16.5	5.5	17.3
S	0.8	0.06	0.2	0.4	2	–
P_2O_5	<0.1	1.7	0.3	0.1	–	–
MnO	0.3	5.3	7.9	1	–	0.2

* OPC: Ordinary Portland Cement

Unit: %

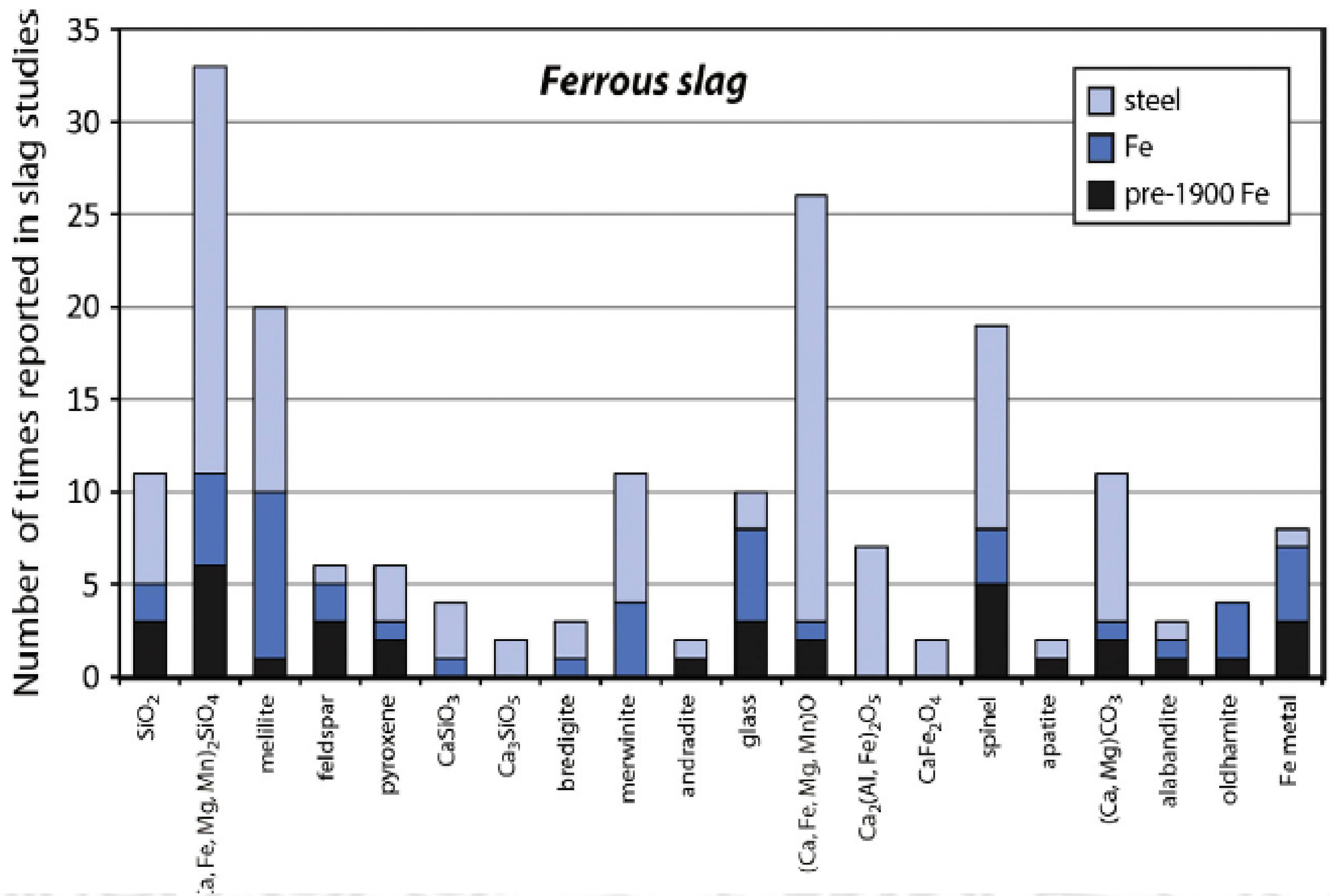
Zloženie trosiek - príklady

Element	*mg/kg*	*Element*	*mg/kg*
Fe	242000	Zn	244
Ca	221000	Nb	198
Al	219000	Sr	178
Si	57700	Cu	166
Mg	45200	Zr	55.2
Mn	39300	Ni	45
Cr	7760	Pb	21.5
P	4600	Mo	20.6
Na	3700	Sn	17.5
Ti	2800	Co	5.8
Si	1260	As	5.3
V	1210	Cd	0.45
Ba	728	Be	<1.2
K	460	Hg	<0.41
W	410		

Fázové zloženie trosiek

Reference	Slag	Mineralogical phases
Barra et al. [16]	EAF	$CaCO_3$, FeO, MgO, Fe_2O_3, $Ca_2Al(AlSiO_7)$, Ca_2SiO_4
Geiseler [29]	—	$2CaO \cdot SiO_2$, $3CaO \cdot SiO_2$, $2CaO \cdot Fe_2O_3$, FeO, (Ca, Fe)O (calciowustite), (Mg, Fe)O (magnesiowustite), free MgO, CaO
Juckes [8]	BOF	C_3S, C_2S, C_2F, RO phase (FeO-MgO-CaO-FeO), MgO, CaO
Luxán et al. [17]	EAF	Ca_2SiO_5, $Ca_2Al(AlSiO_7)$, Fe_2O_3, $Ca_{14}Mg_2(SiO_4)_8$, $MgFe_2O_4$, Mn_3O_4, MnO_2
Manso et al. [28]	Ladle	Al_2O_4Mg, $Ca(OH)_2$, Si_2O_6CaMg, MgO, Ca_3SiO_5, β-Ca_2SiO_4, γ-Ca_2SiO_4, SO_4Ca
Nicolae et al. [20]	BOF	$2CaO \cdot Al_2O_3 \cdot SiO_2$, Fe_2O_3, CaO, FeO
Nicolae et al. [20]	EAF	MnO_2, MnO, Fe_2SiO_4, Fe_7SiO_{10}
Nicolae et al. [20]	Ladle	$CaO \cdot SiO_2$, $CaOAl_2O_3 \cdot 2SiO_2$, CaS, Al_2O_3
Qian et al. [21]	EAF	γ-Ca_2SiO_4, C_3MS_2, CFMS, FeO-MnO-MgO solid solution
Qian et al. [21]	Ladle	γ-Ca_2SiO_4, C_3MS_2, MgO
Reddy et al. [25]	BOF	$2CaO \cdot Fe_2O_3$, $2CaO \cdot P_2O_5$, $2CaO \cdot SiO_2$, CaO
Reddy et al. [25]	BOF[q]	$2CaO \cdot Fe_2O_3$, $3CaO \cdot SiO_2$, $2CaO \cdot SiO_2$, Fe_2O_3
Tossavainen et al. [13]	Ladle	$Ca_{12}Al_{14}O_{33}$, $MgO \cdot \beta$-Ca_2SiO_4, γ-Ca_2SiO_4, $Ca_2Al_2SiO_7$
Tossavainen et al. [13]	BOF	β-Ca_2SiO_4, FeO-MnO-MgO solid solution, MgO
Tossavainen et al. [13]	EAF	$Ca_3Mg(SiO_4)_2$, β-Ca_2SiO_4, Spinel solid solution $(Mg, Mn)(Cr, Al)_2O_4$, wustite-type solid solution ((Fe, Mg, Mn)O), $Ca_2(Al, Fe)_2O_5$
Tsakiridis et al. [19]	EAF	Ca_2SiO_4, $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$, $Ca_2Al(AlSiO_7)$, Ca_3SiO_5, $2CaO \cdot Al_2O_3 \cdot SiO_2$, FeO, Fe_3O_4, MgO, SiO_2
Wachsmuth et al. [30]	BOF	Ca_2SiO_4, Ca_3SiO_5, FeO, $2CaO \cdot Fe_2O_3$

Fázové zloženie trosiek



Porovnanie trosiek

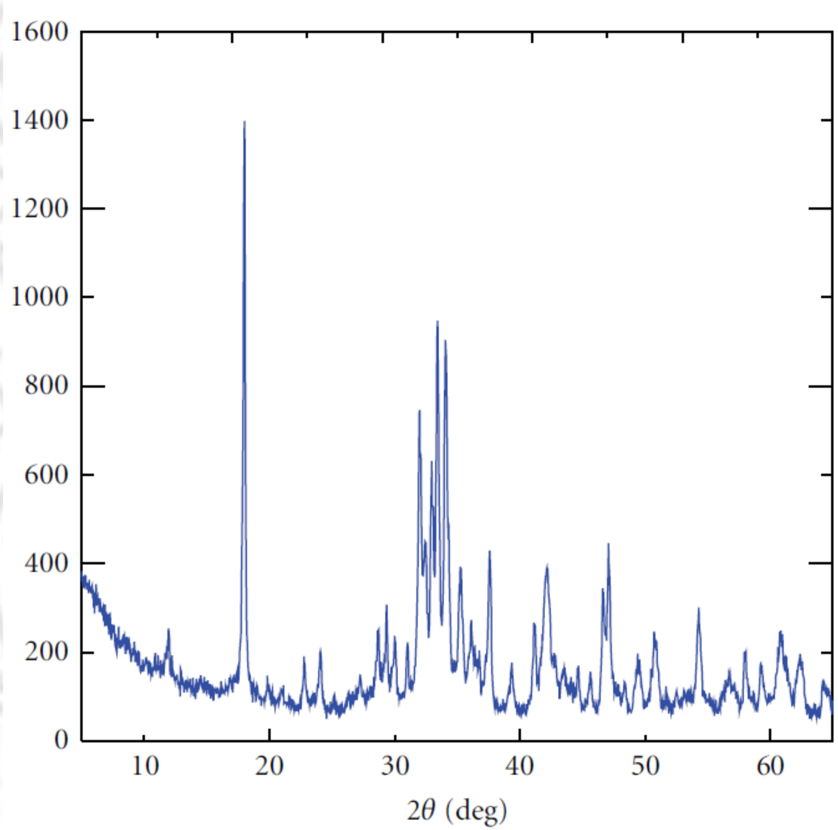
Oxides	% (by weight)
CaO	39.40
FeO	30.23
SiO_2	11.97
MgO	9.69
MnO	2.74
Al_2O_3	2.16
P_2O_5	1.00
TiO_2	0.40
Na_2O	0.25
Cr_2O_3	0.20
K_2O	0.05
Cl	0.01
SO_3	0.12
L.O.I.[a]	1.80

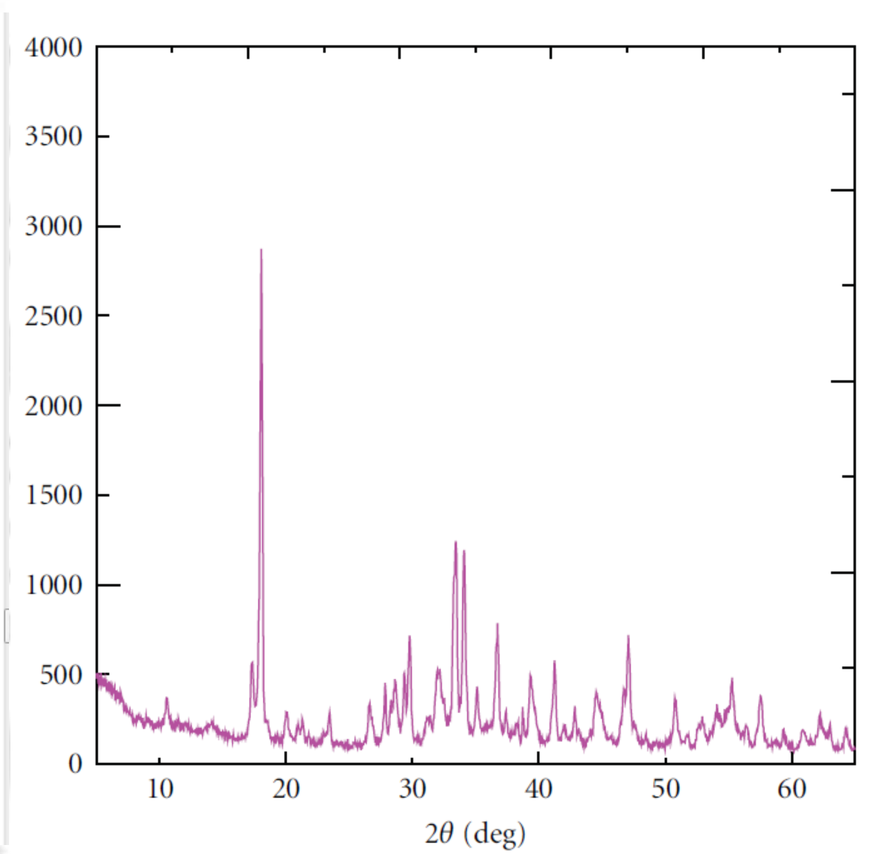
BOF troska

Oxides	% (by weight)
CaO	47.52
Al_2O_3	22.59
FeO	7.61
MgO	7.35
SiO_2	4.64
SO_3	2.28
MnO	1.00
Cr_2O_3	0.37
TiO_2	0.33
P_2O_5	0.09
Na_2O	0.06
K_2O	0.02
Zn	0.01
L.O.I[a]	6.20

EOP troska

RTG fázová analýza





BOF troska

EOP troska

Zloženie trosiek

- ***Oxidy Si, Ca, Mg, Fe, Mn, ...***
  - Sklá, inertný materiál, stavebníctvo

- ***Minority***
  - materiálová recyklácia
  - **ďalšie možnosti !!!**

Zloženie - minority

kov [ppm]	oceliarenská troska						
	konvertor	EOP	panva		konvertor	EOP	panva
Nb	30.4	146	2.5	**Eu**	1.74	0.15	0.31
Ta	1	22	0.2	**Gd**	6.96	0.8	1.6
Sc	14	1	3	**Tb**	1.13	0.1	0.2
Y	34.2	4.1	13.8	**Dy**	6.58	0.9	1.6
La	36.6	9.4	12.7	**Ho**	1.29	0.1	0.3
Ce	73	18.1	26.3	**Eu**	3.62	0.5	0.8
Pr	8.55	2	3.4	**Tm**	0.5	*nd*	0.1
Nd	31.3	8.4	12.4	**Yb**	3.16	0.3	0.7
Sm	6.83	0.9	1.8	**Lu**	0.48	*nd*	0.1
				# PVZ	*261.34*	*214.75*	*81.87*

Vlastnosti a možnosti trosiek

References	Slag type
Ali et al. (2013)	Cu
Altepeter and James (1992)	Zn
Álvarez-Valero et al. (2008)	Base metals (Cu, Pb, Zn)
Álvarez-Valero et al. (2009)	Base metals (Cu, Pb, Zn)
Barca et al. (2012)	Steel
Barna et al. (2004)	Pb, Zn
Bäverman et al. (1997)	Steel
Bayless and Schulz (2003)	Fe, steel
Bayless et al. (1998)	Fe, steel
Bosso and Enzweiler (2008)	Pb
Bril et al. (2008)	Zn
Butler (1977)	Fe
CDM Fed Programs Corp. (1993)	Base metals
Chaudhuri and Newesely (1993)	Pb–Zn
Chaurand et al. (2006)	Steel
Chaurand et al. (2007)	Steel
Chirikure et al. (2010)	Sn
Costagliola et al. (2008)	Base metals (pyrite, Cu–Pb–Zn, Ag), Fe
Cravotta (2005)	Fe
De Andrade Lima and Bernardez (2011)	Pb
De Angelis and Medici (2012)	Pb–Zn
De Windt et al. (2011)	Steel
Douglas and Zerbino (1986)	Fe
Douglas et al. (2012)	Steel
Drizo et al. (2002)	Steel
Drizo et al. (2006)	Steel
Ettler et al. (2000)	Pb–Zn
Ettler et al. (2001a)	Pb–Zn
Ettler et al. (2001b)	Pb–Zn
Ettler et al. (2002)	Pb–Zn
Ettler et al. (2003)	Pb–Ag, Ag–Pb, Pb, Pb–Zn
Ettler et al. (2004)	Pb–Ag, Ag–Pb, Pb, Pb–Zn
Ettler et al. (2005)	Pb–Zn
Ettler et al. (2009a)	Pb–Ag–Zn
Ettler et al. (2009b)	Cu–Pb, Cu
Ettler et al. (2012)	Cu
EUROSLAG (2003)	Fe
Fällman and Hartlén (1994)	Steel
FHWA (1997)	Steel, Cu, P, Ni, Pb
Gahan et al. (2009)	Steel
Ganne et al. (2006)	Zn
Gbor et al. (2000)	Ni
Gee et al. (1997)	Pb
Heimann et al. (2010)	Sn
Ivanov (2000)	Fe, steel, Cu, Pb
Johnson et al. (1982)	Cu
Kierczak et al. (2009)	Ni
Kierczak and Pietranik (2011)	Cu
Kierczak et al. (2013)	Cu
Kourounis et al. (2007)	Steel
Kucha et al. (1996)	Zn–Pb
Lagos and Luraschi (1997)	Cu
Leonard et al. (1977)	Cu, Pb
Lewis (1982)	Fe
Lottermoser (2002)	Base metals (Cu, Cu–Zn, Ag–Pb
Lottermoser (2005)	Pyrite, base metals
Mahé-Le Carlier et al. (2000)	Fe, base metals (Ag, Pb, Cu)
Manasse et al. (2001)	Cu
Manz and Castro (1997)	Ag, Pb, Zn, Cu
Matthes (1980)	Cu
May and Peterson (1991)	Pb
Milačič et al. (2011)	Steel
Morrison and Gulson (2007)	Pb–Zn
Morrison Knudsen Corp. (1992)	Pb
Muhmood et al. (2009)	Fe, steel
Narayan (1995)	Fe
Navarro et al. (2008)	Ag–Pb
Navarro et al. (2010)	Steel
Nelson (1993)	Base metal
Oh et al. (2012)	Steel
Parsons et al. (2001)	Cu–Zn
Partymiller (1992)	Pb
Pérez-López et al. (2008)	Base metals (Cu, Pb, Zn)
Pérez-López et al. (2010)	Base metals (Cu, Pb, Zn)
Piatak et al. (2004)	Cu, Pb–Ag
Piatak and Seal (2010)	Zn
Piatak and Seal (2012a)	Pre-1900 Fe
Piatak and Seal (2014)	Steel
Proctor et al. (2000)	Fe, steel
Puziewicz et al. (2007)	Zn
Rai et al. (2002)	Ferro-Mn
Rizza and Farthing (2007)	Fe
Roadcap et al. (2005)	Steel
Robbins et al. (1983)	Pb, Cu
Rosado et al. (2008)	Base metals (Cu, Pb, Zn)
Sáez et al. (2003)	Cu
Scheinert et al. (2009)	Ag–Pb–Zn–Cu
Scott et al. (1986)	Fe
Seignez et al. (2007)	Pb
Seignez et al. (2008)	Pb
Severin et al. (2011)	Fe
Shen et al. (2009)	Steel
Sidenko et al. (2001)	Zn
Singh et al. (2008)	Fe
Sobanska et al. (2000)	Pb
Suer et al. (2009)	Steel
Svirenko et al. (2003)	Fe
Tack et al. (1993)	Non-ferrous
Tatarinov (2002)	Cu
Tetra Tech Inc (1985)	Cu
Tossavainen et al. (2007)	Steel
Tsakiridis et al. (2008)	Steel
Twidwell (1983)	Cu, Pb
Twidwell and Mehta (1985)	Cu, Pb
Vdović et al. (2006)	Pb–Zn
Vítková et al. (2010)	Cu–Co
Vítková et al. (2011)	Cu–Co
Vivenzio and Farthing (2005)	Fe
Wendling et al. (2010)	Steel
Wendling et al. (2012)	Steel
Wendling et al. (2013)	Fe, steel
West (1902)	Fe
Wilson (1994)	Many
Woodley and Walters (1986)	Pb BFS
Yildirim and Prezzi (2011)	Steel
Ziemkiewicz and Skousen (1999)	Steel

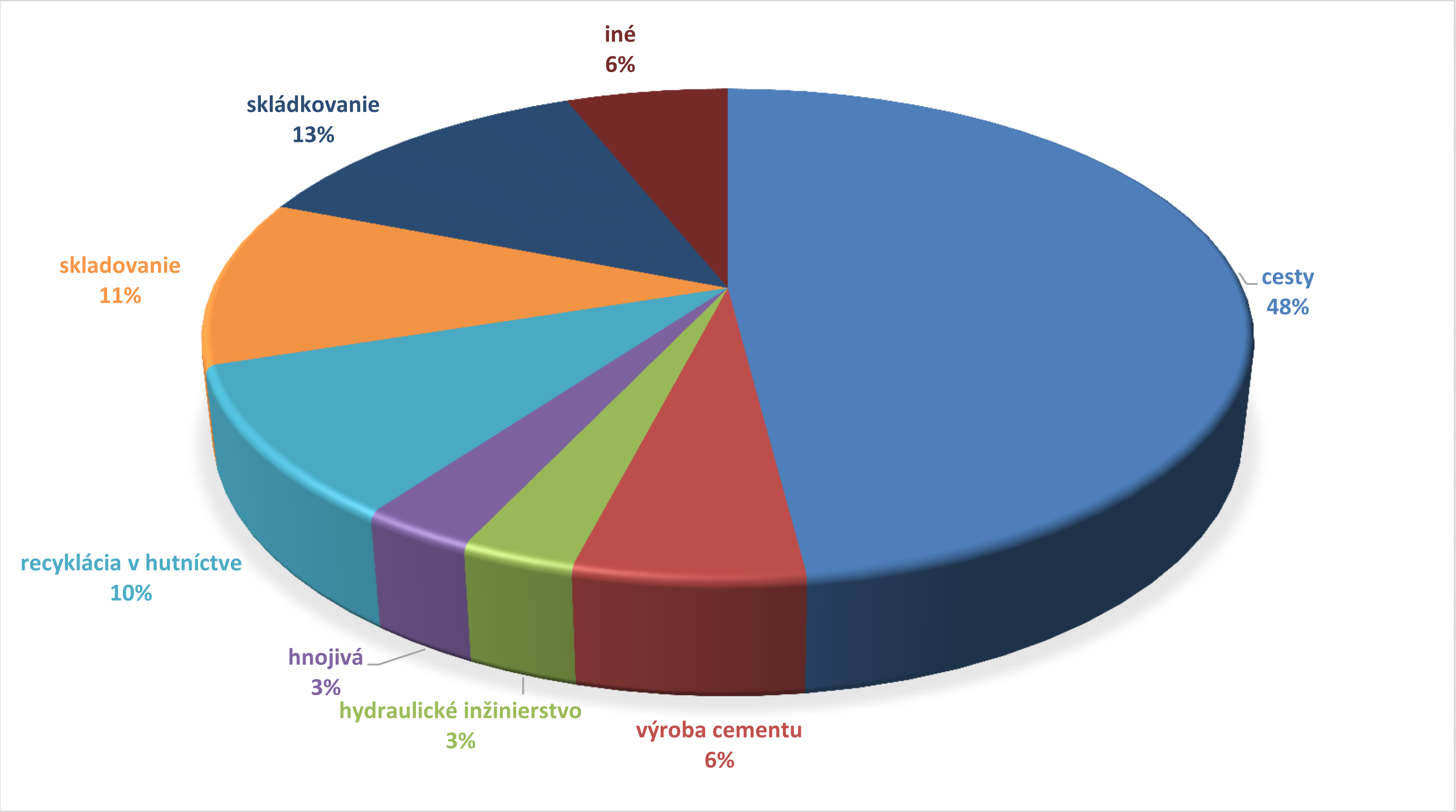
Využitie trosiek

References	Slag type
Ali et al. (2008)	Steel
Anand et al. (1980)	Cu
Anderson (1991)	Ferrous
Baker et al. (1998)	Steel
Blowes et al. (2005)	Steel
Bowden et al. (2009)	Steel
Chang et al. (2013)	Fe
Cravotta (2005)	Fe
Dimitrova (2002)	Fe
Drizo et al. (2002)	Steel
Drizo et al. (2006)	Steel
EUROSLAG (2006)	Ferrous
FHWA (1997)	Steel, Cu, P, Ni, Pb
Gahan et al. (2009)	Steel
Gbor et al. (2006)	Ni
Gbor et al. (2000)	Ni
Gorai et al. (2003)	Cu
Hadjsadok et al. (2012)	Fe
Hanski et al. (2007)	Steel
Hanski and Kankaala (2009)	Steel
Kwon et al. (2008)	Steel
Li et al. (2009)	Cu–Ni
Lopez et al. (1997)	Steel
Lopez Gomez et al. (1999)	Steel
Maslehuddin et al. (2003)	Steel
Negim et al. (2010)	Steel
Ochola and Moo-Young (2004)	Steel
Park et al. (1994)	Steel
Qiu et al. (2012)	Steel
Rao and Nayak (1992)	Cu
Sánchez and Sudbury (2013)	Cu
Shelley (1975)	Non-ferrous
Shibayama et al. (2010)	Non-ferrous
Simmons et al. (2002)	Steel
Srivastava et al. (2005)	Steel
Sun et al. (2009)	Steel
Tshiongo et al. (2010)	Cu
Van Oss (2013)	Ferrous
Weber et al. (2007)	Steel
Yang et al. (2010)	Cu
Ziemkiewicz and Skousen (1999)	Steel

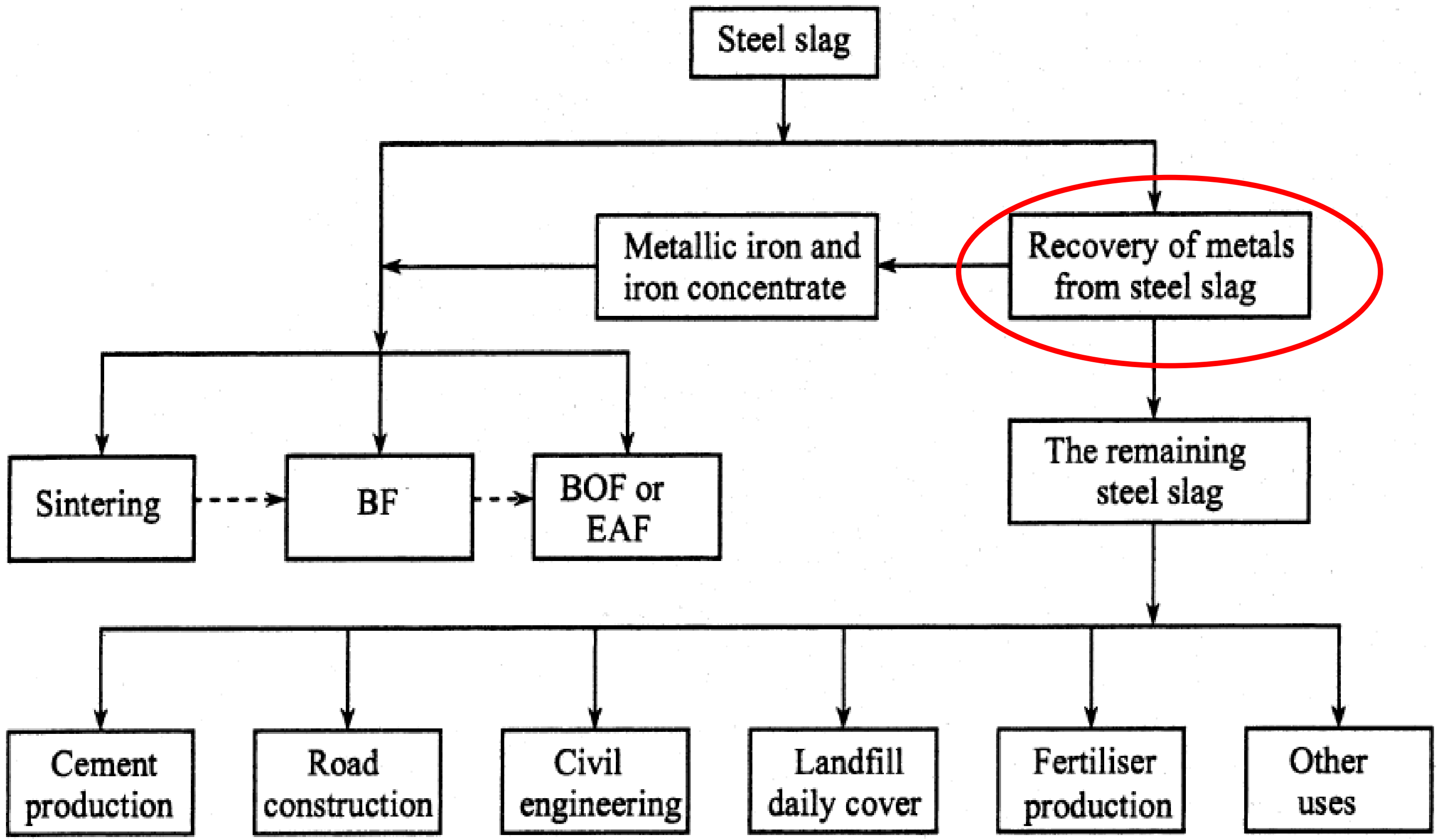
Súčasný stav

- Výroba cementu
- Inžinierske stavby
- Stavebníctvo
- Terénne úpravy
- Posypy
- Umelé hnojivá
- Recyklácia Fe

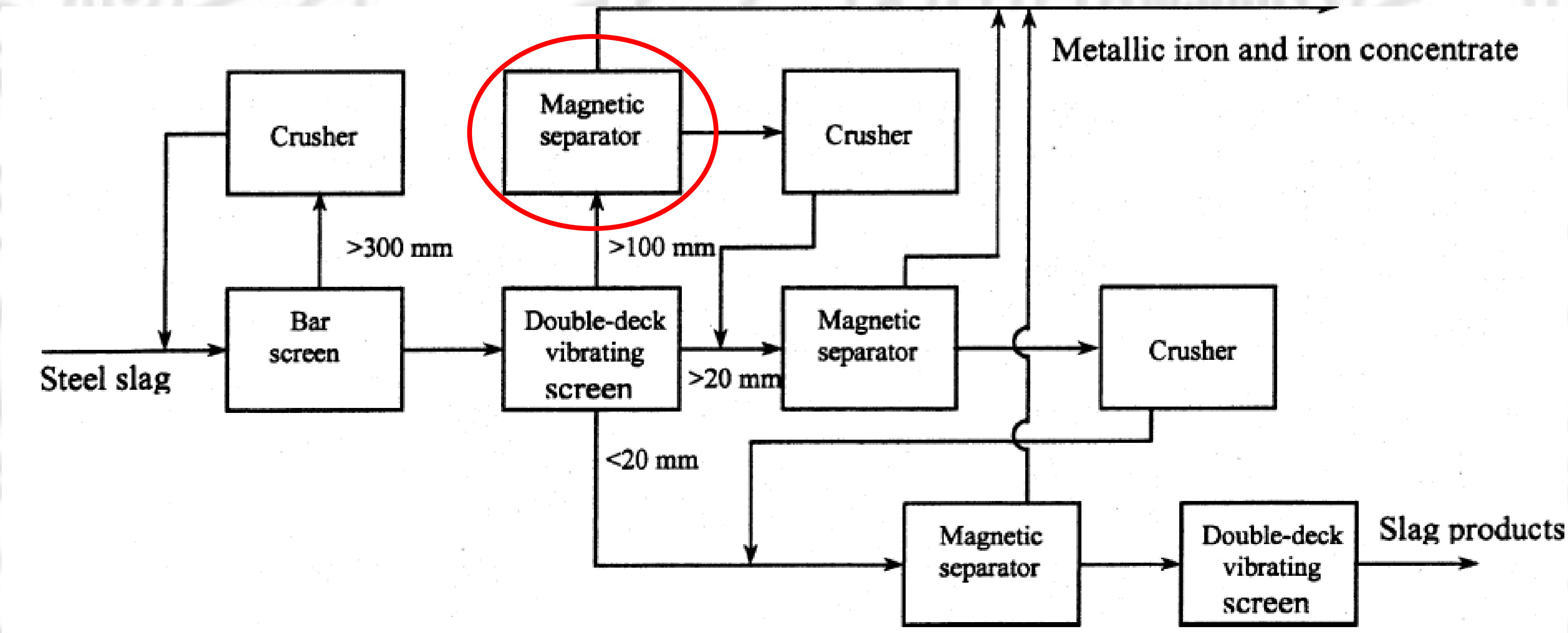
Využitie trosiek



Spracovanie trosiek



Získavanie kovov z trosky



Získavanie kovov z trosky

Využitie oceliarenskej trosky:

Harsco Metals

Získavanie kovov z trosky

Využitie oceliarenskej trosky:

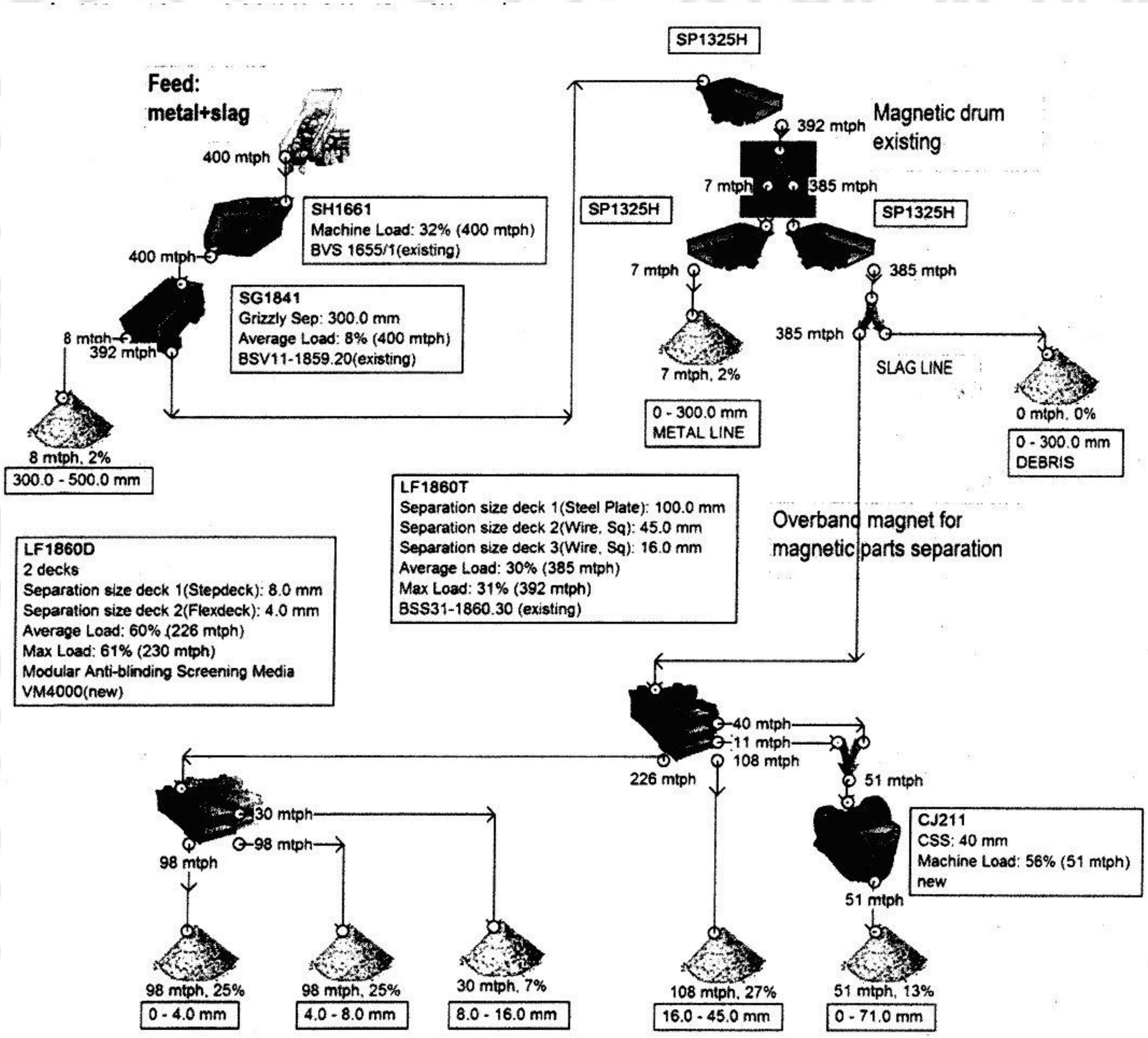
Phoenix Services Slovensko s.r.o.

Získavanie kovov z trosky

Využitie oceliarenskej trosky:

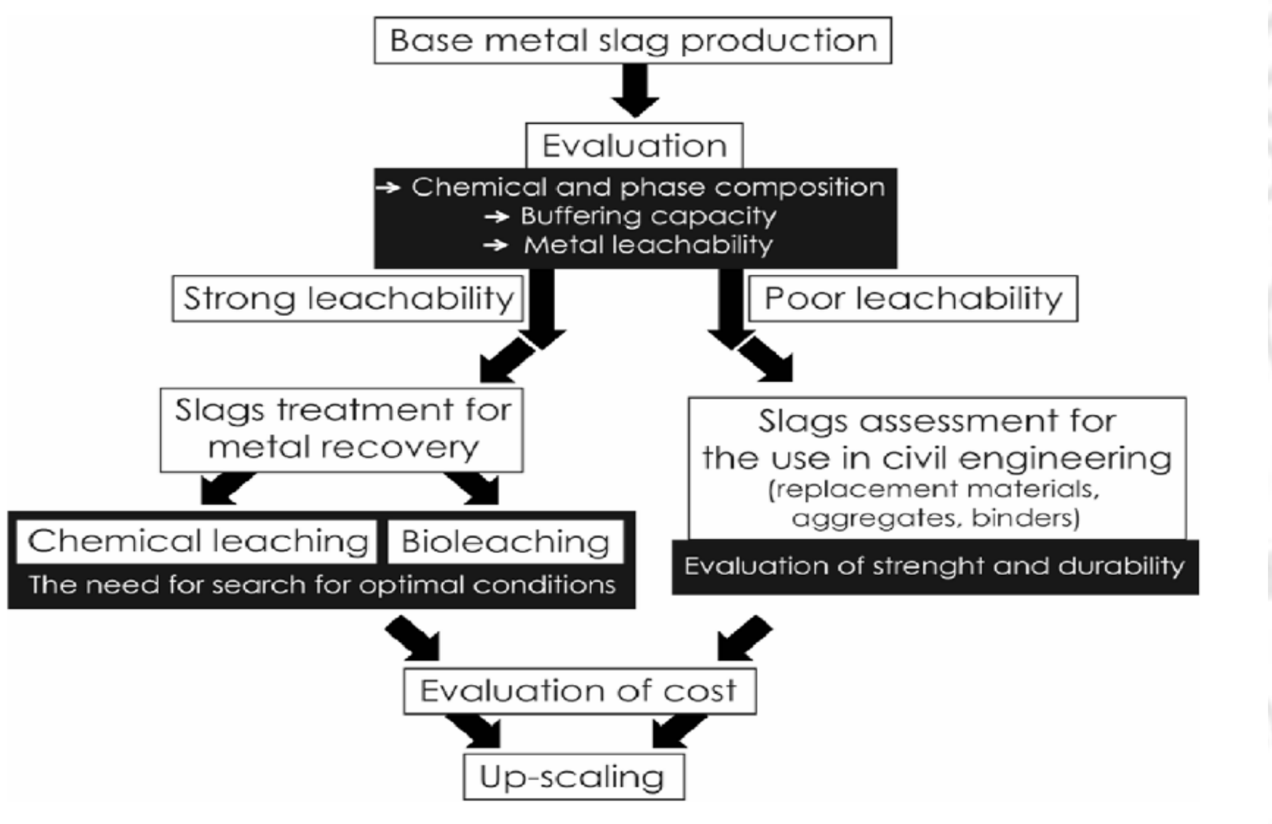
Phoenix Services Slovensko s.r.o.

Schéma Harsco



Perspektívy

Získavanie ďalších zaujímavých kovov



Vstupné úvahy

kov	obsah [%]	cena [US$/t]	priemer
Fe	0.5-30	55-70	20
Si	0.5-6	6700	3.5
Mg	4.5	2500	4
Ca	3-22	22000	13
Al	0.2-22	1860	10
Hg	<4*10-7	2000	0.0000003
Mn	0.8-6	2060	3.4
As	5.3*10-6	2400	0.0000053
Pb	<0.4	2601	0.3
Zn	2.5*10-4	2788	0.00025
Ti	<0.04	4800	0.03
Cu	<0.4	6420	0.03
Cr	0.3-6 (17)	10000	10
Ni	0.3-4.5	13160	2.4
Cd	4.5*10-7	18500	0.0000004
Mo	0.05-1	26000	0.3
W	0.2-4	30300	2.1
Co	0.2-1	33000	0.6
Nb	<0.5	42280	0.1
Ce	4*10-5	60000	0.00002
V	0.05-1 (6)	88000	0.2
Ta	2.2*10-6	151800	0.0000011
PVZ	2*10-4		0.0002
	Ta	151800	
	Sc	20000000	
	Y	75000	
	La	37000	
	Ce	37000	
	Pr	660000	
	Nd	45000	
	Sm	5000000	
	Eu	10000000	
	Gd	14600000	
	Tb	15000000	
	Dy	4700000	
	Ho	650000	
	Er	17500000	
	Tm	1000000	
	Yb	150000	
	Lu	3000000	

Vstupné úvahy

kov	obsah [%]	cena [US$/t]	priemer	výnos [US$/t]
Fe	0.5-30	55-70	20	12
Si	0.5-6	6700	3.5	234
Mg	4.5	2500	4	100
Ca	3-22	22000	13	2860
Al	0.2-22	1860	10	186
Hg	<4*10-7	2000	0.0000003	0.0006
Mn	0.8-6	2060	3.4	70
As	5.3*10-6	2400	0.0000053	0.12
Pb	<0.4	2601	0.3	7.8
Zn	2.5*10-4	2788	0.00025	0.69
Ti	<0.04	4800	0.03	0.14
Cu	<0.4	6420	0.03	1.92
Cr	0.3-6 (17)	10000	10	1000
Ni	0.3-4.5	13160	2.4	316
Cd	4.5*10-7	18500	0.0000004	0.0074
Mo	0.05-1	26000	0.3	0.78
W	0.2-4	30300	2.1	636.3
Co	0.2-1	33000	0.6	198
Nb	<0.5	42280	0.1	42.2
Ce	4*10-5	60000	0.00002	0.01
V	0.05-1 (6)	88000	0.2	17.6
Ta	2.2*10-6	151800	0.0000011	0.16
PVZ	2*10-4		0.0002	273
	Ta	151800		
	Sc	20000000		
	Y	75000		
	La	37000		
	Ce	37000		
	Pr	660000		
	Nd	45000		
	Sm	5000000		
	Eu	10000000		
	Gd	14600000		
	Tb	15000000		
	Dy	4700000		
	Ho	650000		
	Er	17500000		
	Tm	1000000		
	Yb	150000		
	Lu	3000000		*priemerná c*

Vstupné úvahy

kov	obsah [%]	cena [US$/t]	priemer	výnos [US$/t]	poradie absolútne
Fe	0.5-30	55-70	20	12	13
Si	0.5-6	6700	3.5	234	6
Mg	4.5	2500	4	100	9
Ca	3-22	22000	13	2860	1
Al	0.2-22	1860	10	186	8
Hg	<4*10-7	2000	0.0000003	0.0006	23
Mn	0.8-6	2060	3.4	70	10
As	5.3*10-6	2400	0.0000053	0.12	19
Pb	<0.4	2601	0.3	7.8	14
Zn	2.5*10-4	2788	0.00025	0.69	17
Ti	<0.04	4800	0.03	0.14	20
Cu	<0.4	6420	0.03	1.92	15
Cr	0.3-6 (17)	10000	10	1000	2
Ni	0.3-4.5	13160	2.4	316	4
Cd	4.5*10-7	18500	0.0000004	0.0074	22
Mo	0.05-1	26000	0.3	0.78	16
W	0.2-4	30300	2.1	636.3	3
Co	0.2-1	33000	0.6	198	7
Nb	<0.5	42280	0.1	42.2	11
Ce	4*10-5	60000	0.00002	0.01	21
V	0.05-1 (6)	88000	0.2	17.6	12
Ta	2.2*10-6	151800	0.0000011	0.16	18
PVZ	2*10-4		0.0002	273	5
	Ta	151800			
	Sc	20000000			
	Y	75000			
	La	37000			
	Ce	37000			
	Pr	660000			
	Nd	45000			
	Sm	5000000			
	Eu	10000000			
	Gd	14600000			
	Tb	15000000			
	Dy	4700000			
	Ho	650000			
	Er	17500000			
	Tm	1000000			
	Yb	150000			
	Lu	3000000		*priemerná cena PVZ: 544*	

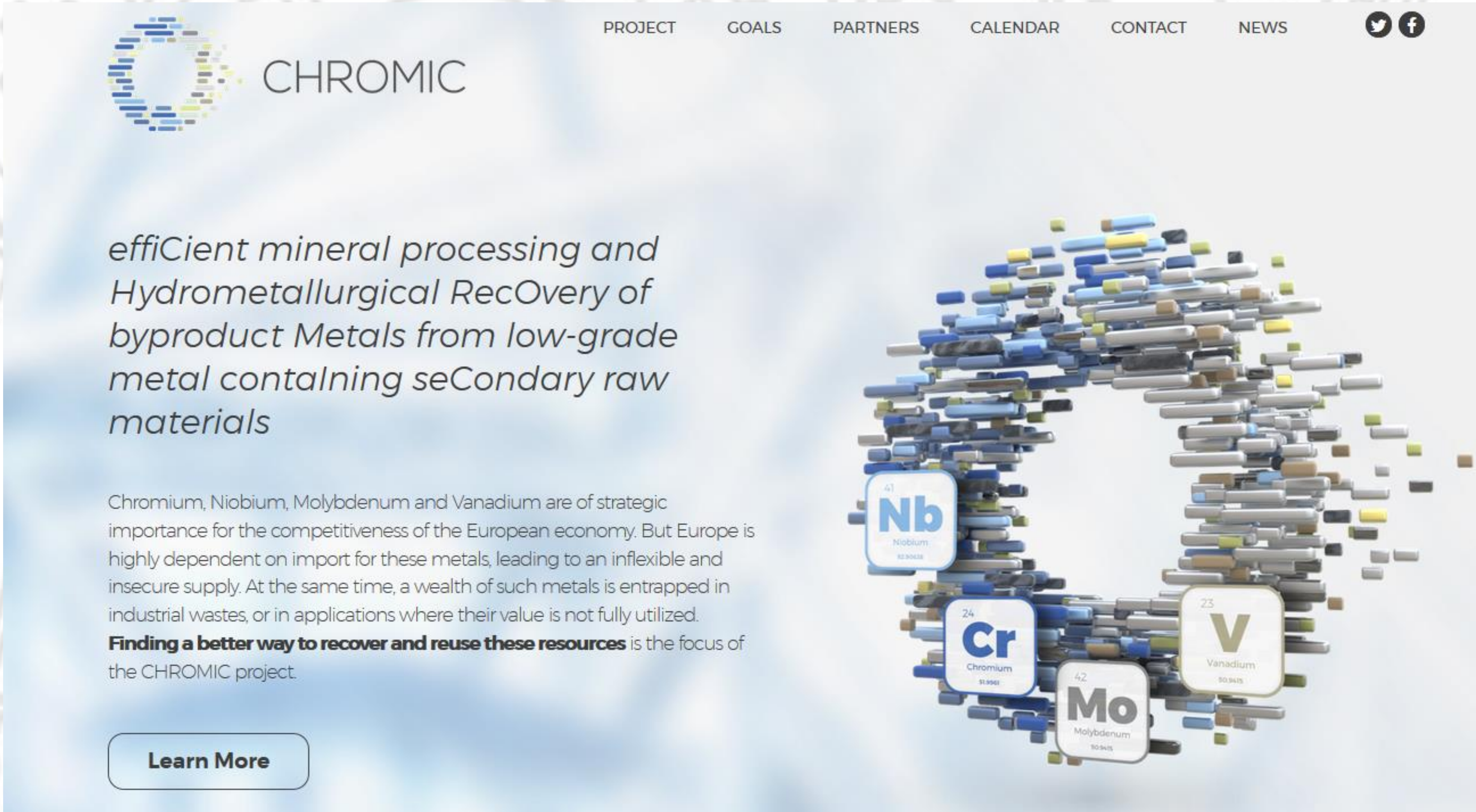
Vstupné úvahy

kov	obsah [%]	cena [US$/t]	priemer	výnos [US$/t]	poradie absolútne	poradie bez oxidov
Fe	0.5-30	55-70	20	12	13	9
Si	0.5-6	6700	3.5	234	6	
Mg	4.5	2500	4	100	9	
Ca	3-22	22000	13	2860	1	
Al	0.2-22	1860	10	186	8	
Hg	<4*10-7	2000	0.0000003	0.0006	23	18
Mn	0.8-6	2060	3.4	70	10	6
As	5.3*10-6	2400	0.0000053	0.12	19	15
Pb	<0.4	2601	0.3	7.8	14	10
Zn	2.5*10-4	2788	0.00025	0.69	17	13
Ti	<0.04	4800	0.03	0.14	20	
Cu	<0.4	6420	0.03	1.92	15	11
Cr	0.3-6 (17)	10000	10	1000	2	1
Ni	0.3-4.5	13160	2.4	316	4	3
Cd	4.5*10-7	18500	0.0000004	0.0074	22	17
Mo	0.05-1	26000	0.3	0.78	16	12
W	0.2-4	30300	2.1	636.3	3	2
Co	0.2-1	33000	0.6	198	7	5
Nb	<0.5	42280	0.1	42.2	11	7
Ce	4*10-5	60000	0.00002	0.01	21	16
V	0.05-1 (6)	88000	0.2	17.6	12	8
Ta	2.2*10-6	151800	0.0000011	0.16	18	14
PVZ	2*10-4		0.0002	273	5	4
	Ta	151800				
	Sc	20000000				
	Y	75000				
	La	37000				
	Ce	37000				
	Pr	660000				
	Nd	45000				
	Sm	5000000				
	Eu	10000000				
	Gd	14600000				
	Tb	15000000				
	Dy	4700000				
	Ho	650000				
	Er	17500000				
	Tm	1000000				
	Yb	150000				
	Lu	3000000		*priemerná cena PVZ: 5447400 US$/t*		

Závery

- ***Recyklovateľné kovy*** – podľa typu trosky:
  - **Železo**: fyzikálno mechanické (FM) spôsoby
  - **Chróm**: FM+PM, FM+HM
  - **Wolfram**: FM + HM
  - **Nikel**: FM + HM
  - **PVZ**: FM + HM

Súčasný stav



CHROMIC

effiCient mineral processing and Hydrometallurgical RecOvery of by-product Metals from low-grade metal containIng seCondary raw materials

COORDINATOR: LIESBETH.HORCKMANS
VITO NV, Belgium, liesbeth.horckmans@vito.be

LIST OF PARTICIPANTS

Participant No	Type of participant	Participant organisation name	Short name	Country
1 (Coord.)	RTO	Vlaamse Instelling voor Technologisch Onderzoek NV	VITO	Belgium
2	SME	MEAM	MEAM	Belgium
3	Industry	Elektrowerk Weisweiler GmbH	EWW	Germany
4	SME	ORBIX Belgium	ORB	Belgium
5	SME	Formicablu srl	FOR	Italy
6	SME	ARCHE cvba	ARCH	Belgium
7	University	Technická Univerzita v Košiciach	TUK	Slovakia
8	RTO	Helmholtz-Zentrum Dresden-Rossendorf EV	HZDR	Germany
9	RTO	VDEH–Betriebsforschungsinstitut GmbH	BFI	Germany
10	RTO	Institut für Baustoff-Forschung EV	FEhS	Germany
11	RTO	Bureau de Recherches Géologiques et Minières	BRGM	France

EUROPEAN
COMMISSION

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SWD(2018) 36 final

PART 1/3

COMMISSION STAFF WORKING DOCUMENT

Report on Critical Raw Materials and the Circular Economy

EN

EN

project will be maintained in the EU Raw Materials Information System (see Section 4.1.1).

3.5. ERECON: The European Rare Earths Competency Network (2013-2015)

The former European Rare Earths Competency Network (ERECON)[31] brought together experts from industry, academia and policy-making to specifically look at ways to improve the security of Europe's **rare earth** supply. Three Working Groups of ERECON were focused on primary supply of rare earths in Europe; European rare earths resource efficiency and recycling; and European end-user industries and rare earths supply trends and challenges. Key findings of the network were compiled into a final report[32].

3.6. Other Horizon 2020 and LIFE projects

Together with the SCRREEN coordination and support action a number of **Horizon 2020** research and innovation actions are currently investigating the potential substitution of CRMs. **INREP**[33] and **INFINITY**[34] are working towards indium-free transparent conducting oxides. **Flintstone2020**[35] deals with the next generation of superhard non-CRM materials and solutions in tooling substituting tungsten and cobalt.

In the area of industrial symbiosis, **SCALE**[36] aims to develop a European supply chain for scandium through the development of technological innovations which will allow the extraction of scandium from bauxite residues, the **CHROMIC**[37] project aims to develop a new recovery process for critical by-product metals (niobium and vanadium) from complex and low-grade secondary industrial waste, **CABRISS**[38] aims at the recovery and preparation for reuse of key photovoltaic raw materials including silicon and indium, to be used for the manufacturing of photovoltaic cells and panels or as feedstock for other industries and **REslag**[39] is addressing, among other things, CRMs to be extracted from steel slag.

The **LIFE Programme** (2014-2020) also contributes to sustainable use, recovery and recycling of raw materials. It is currently funding a cluster of projects dealing with CRMs such as indium, platinum group metals and magnesium. Examples of such projects are the **CRM Recovery**[40] that is demonstrating viable approaches to increase the recovery of target CRMs found in waste electrical and electronic equipment through trials in Italy, Germany, the UK and the Czech Republic and the **RECUMETAL** project[41] that is demonstrating the recycling of flat panel displays to recover plastics, indium and yttrium and their reuse in new applications.

31 https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en

"*Strengthening of the European Rare Earths Supply Chain - Challenges and policy options*", http://ec.europa.eu/DocsRoom/documents/10882/attachments/1/translations

33 http://www.inrep.eu

34 https://infinity-h2020.eu

35 http://flintstone2020.eu

36 http://scale-project.eu/

37 http://www.chromic.eu/

38 https://www.spire2030.eu/cabriss

39 http://www.reslag.eu

40 http://www.criticalrawmaterialrecovery.eu/

41 https://life-recumetal.eu/en/

Riešenie

CHROMIC

- Cr, Nb, V, Mo, inertný materiál
- výsledky obecne aplikovateľné na trosky
- **SK:** Železiarne Podbrezová, a.s.,

  SSM Strážske

Poďakovanie

The CHROMIC project received funding from the European Union’s Horizon 2020 Research and Innovation program under Grant Agreement n° 730471. The authors wish to thank all project partners for their contribution: VITO, MEAM, Electrowerk Weisweiler, Orbix, Formicablu, ARCHE, HZDR, BFI, FehS, BRGM (www.chromic.eu).

Projekt APVV č. APVV-14-0591: Spracovanie priemyselných odpadov s cieľom získať predajné produkty na báze zinku, cínu a olova

Projekt LSPO - súčasť riešenia úlohy ŽP VVC s.r.o. : Spracovanie odpadov metalurgického procesu v ŽP a.s. – ENVIROMENT


Ďakujem za pozornosť