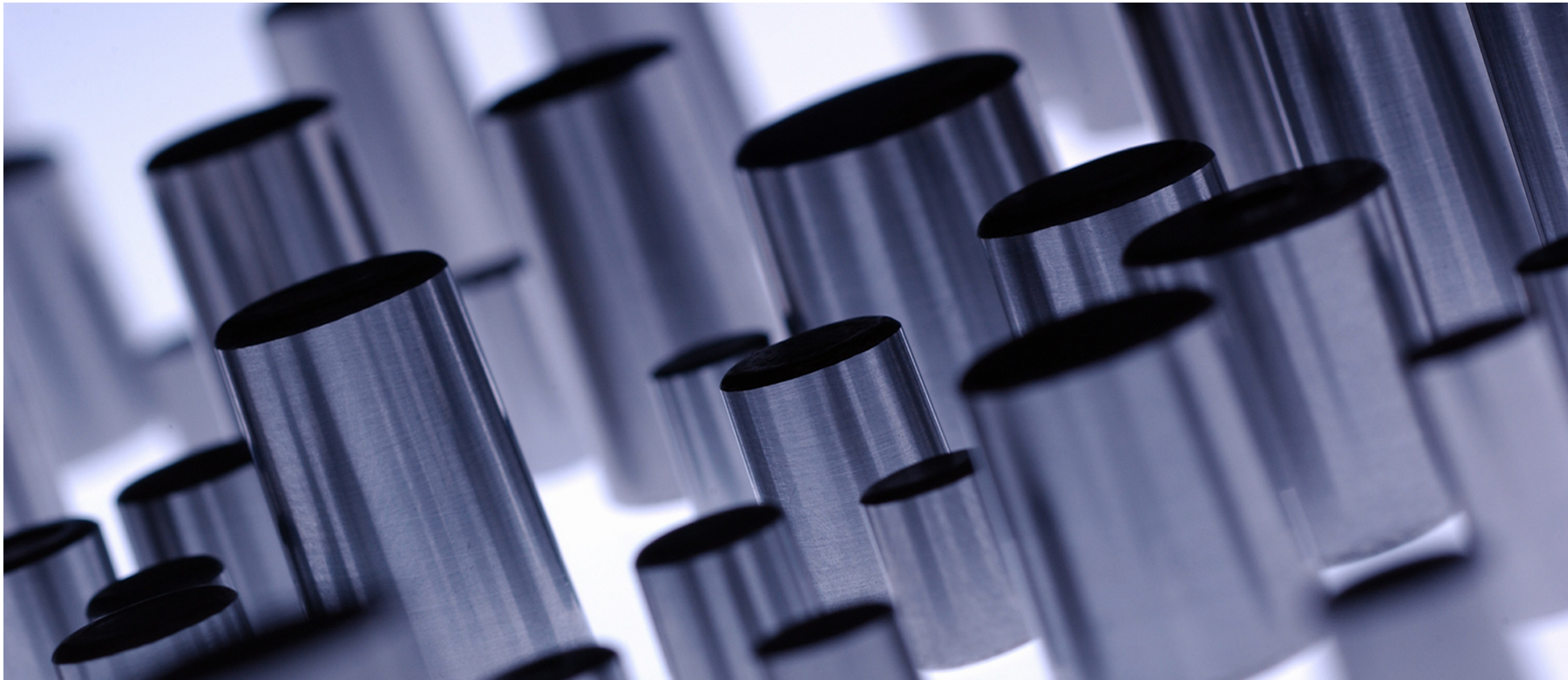
worldsteel ASSOCIATION

New Approach to Untying the Slag Knot

Yu-Chen Andre LEE, Fellow, ECO 13-16 June, 2016



Disclaimer

For presentations to the general public:

This document is protected by copyright. Distribution to third parties or reproduction in any format is not permitted without written permission from worldsteel. worldsteel operates under the strictest antitrust guidelines. Visit worldsteel.org\About us for detailed antitrust guidelines.

For presentations containing preliminary information to members:

The contents of this document are for discussion only and have not been formally approved. Distribution to third parties or reproduction in any format is not permitted.

For presentations to members, confidential:

This document is for worldsteel member companies only. Please do not distribute it to third parties.

For presentations to members, non confidential:

The material in this document is protected by copyright. Use, distribution to third parties or reproduction in any format is allowed, provided worldsteel is acknowledged as the source of the information.

Contents

worldsteel ASSOCIATION

Introduction to “steel slag management-literature study” project

Introduction to “steel slag management-literature study” project

a) Communicate with worldsteel/ECO members to understand their needs and wishes. → Prepare questionnaire

b) Identify gaps in existing knowledge and suggest follow-up action

c) Evaluate maturity and use of the techniques/practices

d) Assist members to improve steel / slag making processes, steel slag quality (high pH & volumetric expansion) and find new/alternative uses for steel slag.

e) Collect public and non-public information and create of steel slag catalogue on Extranet.

An overview of survey analysis

Context of questionnaire & data analysis

- A questionnaire covered pre-treatment, BOF, secondary refining and EAF slags. Data collection involved generation rate, handling and treatment process, destination of recycling and legislation etc.

- Survey participants: **39 steel plants** + **Nippon Slag Association**
- **Annual steel production of participants: 146 million tonnes**

⇨ **9 % of 2015 world production (1623 million tonnes)**

Sum of crude steel produced by the participants	Numbers of participants produced by BOF process	Numbers of participants produced by EAF process	Numbers of participants produced by BOF and EAF process	Members of total participants
120,774,944	15	-	6	39
25,654,261	-	18		

Survey participants :

voestalpine ONE STEP AHEAD.

GERDAU

İSDEMİR

NIPPON SLAG ASSOCIATION

Votorantim Siderurgia

VSB

vallourec

ArcelorMittal

USIMINAS

VALLOUREC & SUMITOMO TUBOS DO BRASIL

ILVA

HBIS 河钢集团有限公司

SSAB

Siderca Tenaris Group

SINOBRAS

CHINASTEEL

中龍鋼鐵 DRAGON STEEL

JSW Steel

Ternium

Ternium Siderar

CELSA GROUP CELSA STEEL UK

CELSA GROUP NERVACERO

TATA STEEL

CELSA GROUP GLOBAL STEEL WIRE

CELSA GROUP CELSA BARCELONA

CELSA GROUP CELSA NORDIC

CELSA GROUP CELSA HUTA OSTROWIEC

BAOSTEEL

posco

CSN Companhia Siderúrgica Nacional

USS U. S. Steel Košice

سابك sabic

Regions distribution of participants

BOF/ Integrate steel plant								
Europe					America	Asia		
Central Europe	Eastern Europe	Western Europe	Southern Europe	Nordic	Latin America	China	East Asia	South Asia

EAF steel plant					
Europe				America	Asia
Eastern Europe	Western Europe	Southern Europe	Nordic	Latin America	Middle East Asia

Countries distribution of participants (7 of the 12 largest steel producing countries)

1	2	3	4	5	6	7	8	9	10	11	12
China	Japan	India	USA	Russia	South Korea	Germany	Brazil	Turkey	Ukraine	Italy	Taiwan
✓	○	✓	-	-	✓	-	✓	✓	-	✓	✓

(Japanese static information provided by Nippon Slag Association)

Pre-treatment slag – generation (1/8)

- Percentage of crude steel for pre-treatment

Do not need pre-treatment		18%
Subject to Pre-treatment process in 82%	Desulfurization(De-S)	81.7%
	De-S plus De-P	0.3%
	De-S + De-P + De-Si	0%

- Ratio for TPC injection and KR impeller desulfurilization

Pre-treatment process	torpedo car injection desulfurizaion	66%
	Kanbara Reactor impeller desulfurization	15%

- Pre-treatment slag generation (dry base):

Pre-treatment slag generation (kg/ton of crude steel)	Top 20% lowest rate average
19 ± 9	8.4

Pre-treatment slag – generation rate & processing (2/8)

- Specific generation of TPC injection and KR impeller De-S slag:

Specific generation (kg/Ton of crude steel)			
TPC injection De-S slag		Kanbara Reactor impeller De-S slag	
20 ± 9	8.4 (Top 20% lowest rate average)	26 ± 7	14 (Top 20% lowest rate average)

- Common processing for De-S slag handling:

  Water cooling → crushing → magnetic separation → screening

Pre-treatment slag – **properties** (3/8)

- as-received De-S slag: pH=12.19±0.13

[Measurement of pH value of a solution consists of fine slag aggregates (<1mm) and deionized water (ratio of slag : DI-water in weight = 1:1)]

- Average metallics content in De-S slag

Average metallics content in De-S slag	26%	Internal recycled		External recycled
		In BOF	In sinter Plant	
		50%	27%	23%

Pre-treatment slag – destination of recycling (4/8)

Destination of pre-treatment slag (without metallic)	Ave. (%)
Internal recycling in **sinter plant** (as sinter feed) (the best 100%)	32 ①
% of addition to sinter (the best 4%)	0.77
External- **engineering filling** for land or sea area, respectively (e.g. use of waste in terms of landscape construction.)	27 ②
Landfilling including internal and external (3 companies-100% landfilling)	23 ③
External-as a **raw material for cement** manufacturer	13 ④
Internal and temporary stockpiling	3
Other applications	3
External-CLSM (controlled low strength material) (low strength concrete) for civil engineering construction-hydraulically bound with cement or binder(s)	0.1
External-agricultural application-fertiliser (~20% addition when mixing with soil)	0
External-agricultural application-soil improvement (no mixing)	0
External-aqua cultural application-improvement of pH value of surrounding water	0

Pre-treatment slag – good performance & opposition (5/8)

- **Good performance**

  1) 100% internal reused in sinter plant (4% addition) -- East Asia

  2) 60% Internal reused in sinter plant + 40% recycled in BF
     -- Western Europe

  3) Raw material for cement industry
     -- Latin America(25%), East Asia(50.5%), China(86%)

- **Trend of internal and temporary stockpiling** (comparing with 2014)

  → increasing-2 plants (Latin America-1 & East Asia-1)

- **Specific use has been campaigned against from other industries, or NGO's**

  - in agricultural application

Pre-treatment slag – categorisation (6/8)

- **Categorisation of De-S slag by national/regional legislation**

Among 16 countries/ regions:

Categorisation of De-S slag by national/regional legislation		
Product	**3**	Slovakia India Taiwan
By-product	**4**	Korea, Sweden Finland, India China (north)
End-of-waste	**0**	--
Waste	**7**	Brazil, China (middle) Turkey, Italy France, Germany UK, Belgium Greece

Pre-treatment slag – gap (7/8)

- Gap
  - Recycling destination (comparing with good performance)

    1) 100% landfilling--Central Europe, Nordic, South Asia
    2) 50-100% Engineering filling--South Europe, Nordic, East Asia

  - Legislative limit of Fluorine content in De-S slag

    (Ground water will be contaminated by fluorine composition)

    1) In Western Europe : 0%
    2) In general, F content < 0.2% (majority of steel plants)
    3) F content >15% → two steel plants in southern Europe and Latin America, respectively.

Pre-treatment slag – other limitations (8/8)

Other limitations due to legal or technical issues

1) Opposition from the environmental agencies

Steel plants in Brazil face some opposition, sometimes, from the environmental agencies, for use of non inert residues such as pre-treatment slag in applications such as filling for landscape construction (engineering filling), being usually analysed case by case.

2) In the case of agricultural or aqua culture applications, the content of fluorine in periphery area (not slag itself) needs to meet 400 mg/kg or less (for the warning limits of Zone 1) (Eastern Asia)

BOF & SEC slag – generation rate (1/13)

- Specific generation of BOF slag (dry base):

BOF slag	Range	Ave.	Top 20% performance
Specific generation (kg/ton of crude steel)	65 ~180	105 ± 27	76 ± 11

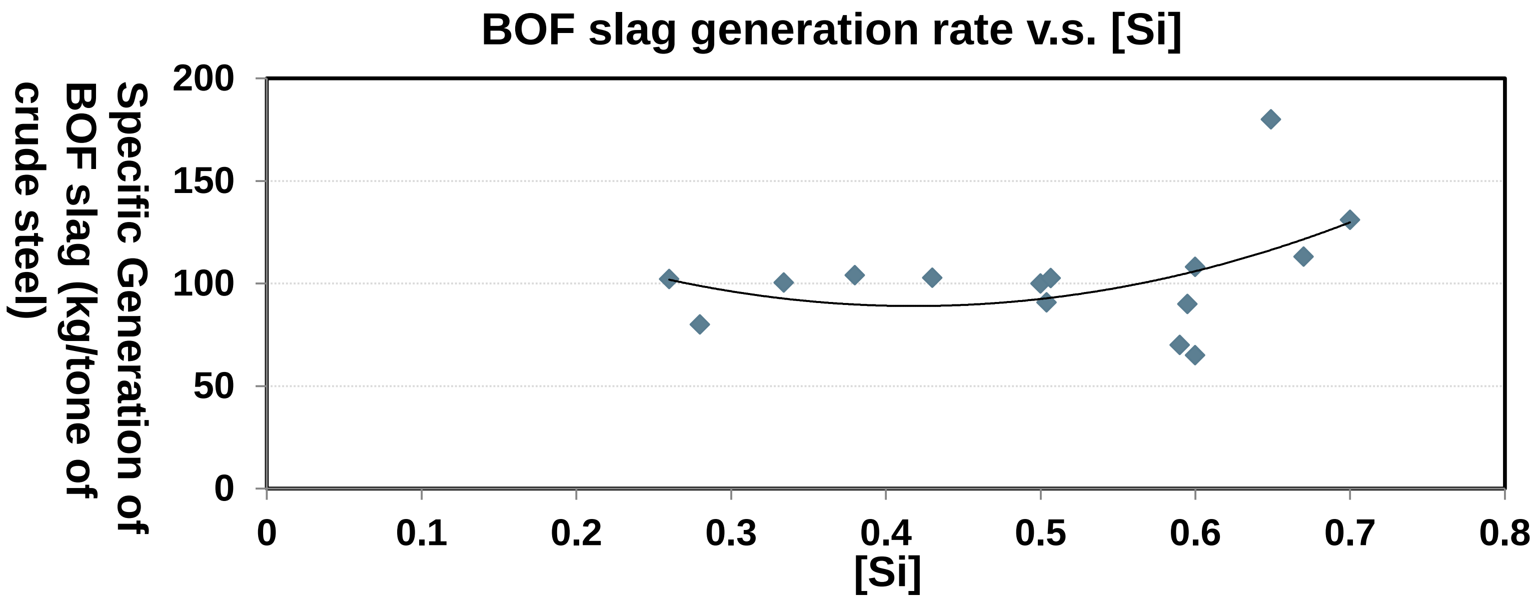
- Specific generation of SEC(BOF) slag (dry base):

SEC slag	Range	Ave.	Top 20% performance
Specific generation (kg/ton of crude steel)	2 ~34	14 ± 8	6 ± 3

BOF & SEC slag – generation v.s. [Si] (2/13)

Average values of [C],[Si],[P],[S] content of liquid iron before BOF blowing process

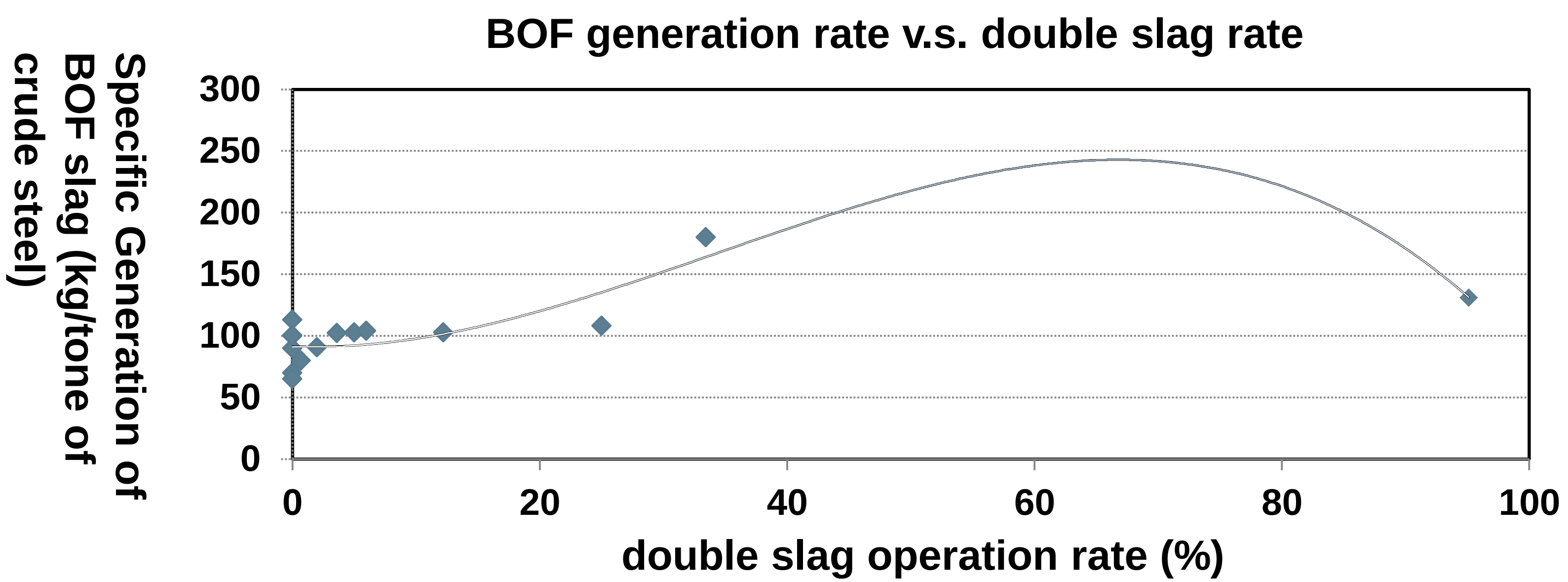
	Ave. ± Stdev.	Range	Best	Top 20% performance
C	4.47±0.19	4.0~4.8	4.0	4.22±0.17
Si	0.48±0.14	0.237~0.7	0.237	0.28±0.04
P	0.10±0.04	0.04~0.174	0.04	0.05±0.01
S	0.03±0.03	0.0024~0.056	0.0024	0.01±0.01



☛ It is expected higher [Si] concentration speeds up reaction of de-P during blowing in BOF. The specific generation of BOF slag is affected by many factors.

BOF & SEC slag – generation v.s. blowing operation (3/13)

Type of blowing operation	Percentage of this survey (%)
Single slag process	81
double slag process	12
Double BOFs process	1.4
Sum	94.5 (5.5% liq. Iron do not need BOF blowing)



☛ It is expected more double slag operation, less BOF slag generation. Based on this figure, it is indicated the specific generation of BOF slag is affected by other factors.

BOF & SEC slag – <u>properties</u> (4/13)

- as-received BOF slag: pH=12.26±0.33

[Measurement of pH value of a solution consists of fine slag aggregates (<1mm) and deionized water (ratio of slag : DI-water in weight = 1:1)]

BOF slag	Ave. ± Stdev.	Range	The Best	Top 20% performance
S %	0.13 ± 0.27	-	-	-
F %	**2.59 ± 7.04**	**0~20**	**0**	**0.03±0.02**
Free CaO	**8.98 ± 6.26**	**3.15~20**	**3.15**	**4.48±0.94**

Gap : One plant in Southern Europe, BOF slag contains 20% of Florine. But in Western Europe, it is restricted Florine content in BOF slag near 0%.

- as-received SEC/BOF slag

SEC slag	Ave. ± Stdev.	The Best	Top 20% performance
S %	0.21 ± 0.18	-	-
F %	**1.41 ± 2.55**	**0**	**0.09±0.08**

BOF slag – processing (5/13)

Percentage of slag quantity is treated by below processes	%	
Pouring onto ground + water spraying	69.27	①
pouring onto ground + natural cooling	16.50	②
BSSF(Baosteel)	6.63	③
Water quenching	5.00	④
Pouring to slag pot + water spraying + water bath	2.36	⑤
Slag modification (e.g. silica sand injection)	0.25	⑥
Steam aging (Japan)	0.00	
Steam pyrolysis (China)	0.00	
Air quenching	0.00	
CO_2 carbonization	0.00	

☛ **Based on expansion evaluation, it is concluded that only modified slag is fully stabilised.**

2-3. BOF & SEC slag – metallics recycling (6/13)

Metallic content in BOF slag			Internal recycling		External recycling
	Range	5~18.3	In BOF	In Sinter Plant	
	Ave.	11 ± 5	71%	12%	17%
	The best	5			
	Top 20%	6 ± 1			

BOF & SEC slag – destination of recycling (7/13)

Destination of de-metallised pre-treatment slag (without metallic)	Ave. (%)
Engineering filling for land or sea area, respectively (e.g. Use of waste in terms of landscape construction.)	19.45 ①
Internal and temporary **stockpiling**	15.98 ②
External- **raw material for cement** manufacturer	13.28 ③
Construction of **footpath**, cycle path or temporary path for vehicle	12.10 ④
Road base	12.07 ⑤
Internal recycling in **sinter** plant (as sinter feed)	7.58 ⑥
(% of addition to sinter)	1.56
Road construction- **Pavement brick**	7.04 ⑦
Internal-powder additive combined with blast furnace cement	0.21
3-1. % of addition to portland cement (as a raw material)	1.29
External-powder additive for portland cement product	2.06
Road construction-Asphalt concrete (AC) (surface pavement)	2.20
Civil engineering construction (e.g. concrete)-hydraulically bound with cement or binder(s) (other than road and bridge application)	2.34
Agricultural application-soil improvement (mixing without anything)	1.62

BOF & SEC slag – destination of recycling (8/13)

Destination of de-metallised pre-treatment slag (without metallics)	Ave. (%)
Marine restoration-unburned pile (slag as received) surrounded by marine block(cement slag mix)	0.01
Hydraulic application-harbor/port waterway dyke (sea dyke) ,river dykes or climate change adaptation works.	0.94
Road/bridge construction-hydraulically bound with cement or binder(s) (for road and bridge only)	0.00
Water quality improvement, mine pit filling, etc.	0.00
Landfilling including internal and external [Waste disposal site for permitted deposition of waste onto or into land including internal waste disposal at a permanent site which is used for temporary storage of waste but excluding recovery operations such as land engineering or engineering fill.(European Definition)]	0.04
other applications	3.33
Agricultural application-fertiliser (~20% addition when mixing with soil)	0.11
Marine restoration-marine block/concrete block, reef building (hydraulically with cement or binders)	0.05

BOF & SEC slag – good performance (9/13)

- **Good performance**

1) Internal reused in sinter plant (1% addition)
   --Western Europe (29%, 1% addition); East Asia (25%, 4% addition)
2) Raw materials for cement industry
   –Latin America (20%), Eastern Europe(26%), China(48%, 92%)
3) Road construction-- Asphalt concrete (AC) (surface pavement)
   -- Latin America (27%)
4) Road construction- Pavement brick
   -- Latin America (100%)
5) Road base--Western Europe(75%), East Asia(35%)(mixed with BF slag)
6) Construction of footpath, cycle path or temporary path for vehicle -- Latin America (94%), East Asia(52%)
7) Civil engineering construction (e.g. concrete)-hydraulically bound with cement or binder(s) (other than road and bridge application) -- East Asia(29%)
8) Agricultural application-soil improvement (mixing without anything)--Nordic (20%)
9) Hydraulic application-harbor/port waterway dyke (sea dyke) ,river dykes or climate change adaptation works -- Western Europe(14%)

BOF & SEC slag – trend of stockpiling & opposition (10/13)

- **Trend of internal and temporary stockpiling** (comparing with 2014)

  → increasing-3 plants (Nordic-1, Western Europe-1, Central Europe-1)

  stay level-3 plants

  decreasing-6 plants

- **Specific use has been campaigned against from other industries, or NGO's**

  - use for landfill cover from mines is limited (lime producers are strong), use in road construction is new area with heavy competition from stone and gravel producers

  - Use in agricultural land

BOF & SEC slag – categorisation (11/13)

- **Categorisation of BOF/SEC slag by national/regional legislation**

Among 18 countries/ regions:

Categorisation of BOF slag by national/regional legislation		
Product	3	Belgium, Slovakia, Taiwan
By-product	9	France-w/h CTPL certificate, Austria, Sweden, Finland, Germany, Netherlands, China (north),Korea, , India
End-of-waste	0	--
Waste	6	Brazil, China-middle, France, Turkey, Netherlands-rest Italy(Stainless BOFS)

→ This is also a gap among different countries or regions.

Authority policy	
Positive	5
negative	1
not specified	7

BOF & SEC slag – <u>gap</u> (12/13)

- Gap
  - Recycling destination

1) Sinter ore--Western Europe(29%), East Asia(25%) v.s. 0%

2) Raw material for cement industry--Latin America, Eastern Europe(20-26%) v.s. East Asia(0%) (limited by Cr_2O_3, MgO content etc.)

3) Agricultural application-soil improvement —Nordic(20%) v.s. East Asia(0%)

BOF & SEC slag – other limitations (13/13)

- **Other limitations due to legal or technical issues**

1) Total Cr limitation (2500 mg/kg DS) when used in asphalt and this asphalt is only allowed to be used in highways. (gap)
2) Total Cr, Cr^{6+}, free CaO and MgO content, volume expansion, heavy metals, legislative obstacles in agricultural, civil engineering, road construction and related area. (gap)
3) NGO/ residents have several concerns: ① Contamination of metallic materials: Cr, Mn, Ba and Ti elements released from the slag. ②High pH value of surface water and groundwater caused by the slag. ③Volumetric expansion of the slag occurred as it is used in the civil engineering material. ④Scientific researches in BOF slag are always questioned resulting from previous bad images on slag issue.
4) Low vanadium concentration limits use in salt water and agriculture applications
5) In the case of agricultural or aqua culture applications, the content of fluorine in periphery area (not slag itself) needs to meet 400 mg/kg or less (for the warning limits of Zone 1).

EAF & SEC slag – generation rate (1/8)

- Specific generation of EAF slag (dry base):

EAF slag	Range	Ave.	Top 20% performance
specific generation (kg/ton of crude steel)	75 ~280	134 ± 5	88 ± 1

- Specific generation of SEC(EAF) slag (dry base):

SEC slag	Range	Ave.	Top 20% performance
specific generation (kg/ton of crude steel)	3 ~79	24 ± 17	6 ± 3

EAF & SEC slag – processing (2/8)

- **Common processing for EAF & SEC slag handling:**

  pouring onto ground + water spraying

  - **other treatment:**

    - BSSF (1 steel plant)
    - Air quenching (1 steel plant)

EAF & SEC slag – properties & metallic (3/8)

- As-received EAF slag: pH=11.12 ± 0.11

  Range from 11.04 to 11.20

[Measurement of pH value of a solution consists of fine slag aggregates (<1mm) and deionized water (ratio of slag : DI-water in weight = 1:1)]

- Sulfur contain is about 0.34%
- Fluorine contain is around 0.42%

- As-received SEC(EAF) slag: pH=12.32 ± 0.25

- Sulphur contain is about 0.72%
- Florine contain is around 1.58%

- Percentage of metallic in EAF slag

Metallic content in EAF slag	Ave.	6 ± 4 %	Internal recycling		External recycling
			In EAF	In Sinter Plant	
			77 %	13%	20%

EAF & SEC slag – destination of recycling (4/8)

Destination of de-metallised EAF & SEC slag (without metallic)	Ave. (%)
Road/bridge construction-hydraulically bound with cement or binder(s) (for road and bridge only)	30.74 ①
Civil engineering construction (e.g. concrete)-hydraulically bound with cement or binder(s) (other than road and bridge application)	16.25 ②
Road base	9.31 ③
Engineering filling for land or sea area, respectively (e.g. Use of waste in terms of landscape construction.)	8.83 ④
Road construction-Asphalt concrete (AC) (surface pavement)	8.09 ⑤
External-powder additive for portland cement product	7.87 ⑥
Construction of footpath, cycle path or temporary path for vehicle	6.12 ⑦
Landfilling including internal and external	4.59 ⑧
Recycling in sinter plant (as sinter feed)	1.9
External-as a raw material for cement manufacturer	3.32
Road construction-Pavement brick	1.03
Internal and temporary stockpiling	1.94
other applications	1.9

EAF & SEC slag – good performance & opposition (5/8)

- **Good performance**

  Construction -- Asphalt concrete (AC) (surface pavement)

  → 3 steel plants 100% (Latin America-1, Middle East-2)

  Road base --

  → 3 steel plants 100% (Eastern Europe-1, Latin America-2)

- **Trend of internal and temporary stockpiling (comparing with 2014)**

  Increasing- 3 plants (Southern Europe-1, Latin America-2)

  Stay level-2 plants

  Decreasing-7 plants

- **Specific use has been campaigned against from other industries, or NGO's**

  - Although it hasn't yet been campaigned against, there's an opposition from gravel pit producers

EAF & SEC slag – categorisation (6/8)

- **Categorisation of EAF slag by national/regional legislation**

Among 20 countries/ regions:

Categorisation of EAF slag by national/regional legislation		
Product	**3**	UK, Norway, Italy-after treatment
By-product	**8**	Sweden; Mexico, Korea, India, Spain, Germany France-w/h CTPL certificate
End-of-waste	**0**	--
Waste	**9**	Taiwan, Poland, France, Brazil, Romania China (middle) Japan(Stainless slag)

→ **This is also a gap among different countries or regions.**

EAF & SEC slag – gap (7/8)

- **Gap**
  - **Recycling destination**

    100% Asphalt concrete (AC) (surface pavement)

    -Latin America-1, Middle East-2

    100% Road base- Eastern Europe-1, Latin America-2

    80% Road base- Latin America-1

    50-60% Road base- Southern Europe-2

    ☛ v.s. 18~23% landfilling- Southern Europe-2

  - **legislative limit of Fluorine content in EAF slag**

    -- In Latin America < 1.5 mg/l (in leaching test)

EAF & SEC slag – other limitations (8/8)

- **Other limitations due to legal or technical issues**

1) Limits in Leachate mg/kg (dry base) - Barium(20);Arsenic(0.5);Cadmium(0.04);Copper(2); Total Chromium(0.5);Mercury(0,01);Nickel(0.4);Lead(0.5); Zinc(4);Molybdenum(0.5);Selenium(0.1);Antimony(0.06); Chloride(800);Fluoride(18);Sulfate(1000)

2) Legislative prohibition of EAF slag usage in agricultural area and structural engineering

3) Lack of compromise/ interest from Government in order to use it in public civil engineering: maximum thickness in road base- 70 cm; Obligation to cover with pavement (asphalt or concrete) in order to limit leachate.

Problems and Countermeasures

Problems and countermeasures

Problems

Countermeasures

- free lime and periclase remain in slag

BOF Steel-making

- Make Slag a product
- Produce slag and steel during steel-making
- Reduce slag quantity and minimize the size of remained free CaO(lime) and MgO(periclase)

Slag problems

- Develop a stable and eco-friendly slag technology
- Switch slag waste to artificial stone

- Expansion
- High pH value

(Leaching test result is acceptable)

Disposal routes are blocked

- Make slag a saleable product
- Develop slag valorization technology

- Legislation status
- NGOs questioned
- Pay money for disposal
- Difficult to dispose

New approach to untying the slag knot

Produce slag as a product during steel-making

Produce slag as a product during steel-making & Reduce slag quantity and minimize the size of remained free CaO/MgO

- **Double slag operation → reduce ~6 kg/tone of crude steel**

Items	De-P efficiency	CaO equivalence	Total slag quantity (kg/tone of crude steel)
Before double slag operation	89.5%	40.84	71.49
After double slag operation	89.7%	33.46	65.88
comparison	+0.2% (keep the same)	–7.38	–5.61

☛Chemical composition of De-Phos slag results from double slag operation characterised by high Phos, Fe_xO_y content and skeleton structure. Therefore not easy to recycle for special application.

Produce slag as a product during steel-making & Reduce slag quantity and minimize the size of remained free CaO/MgO

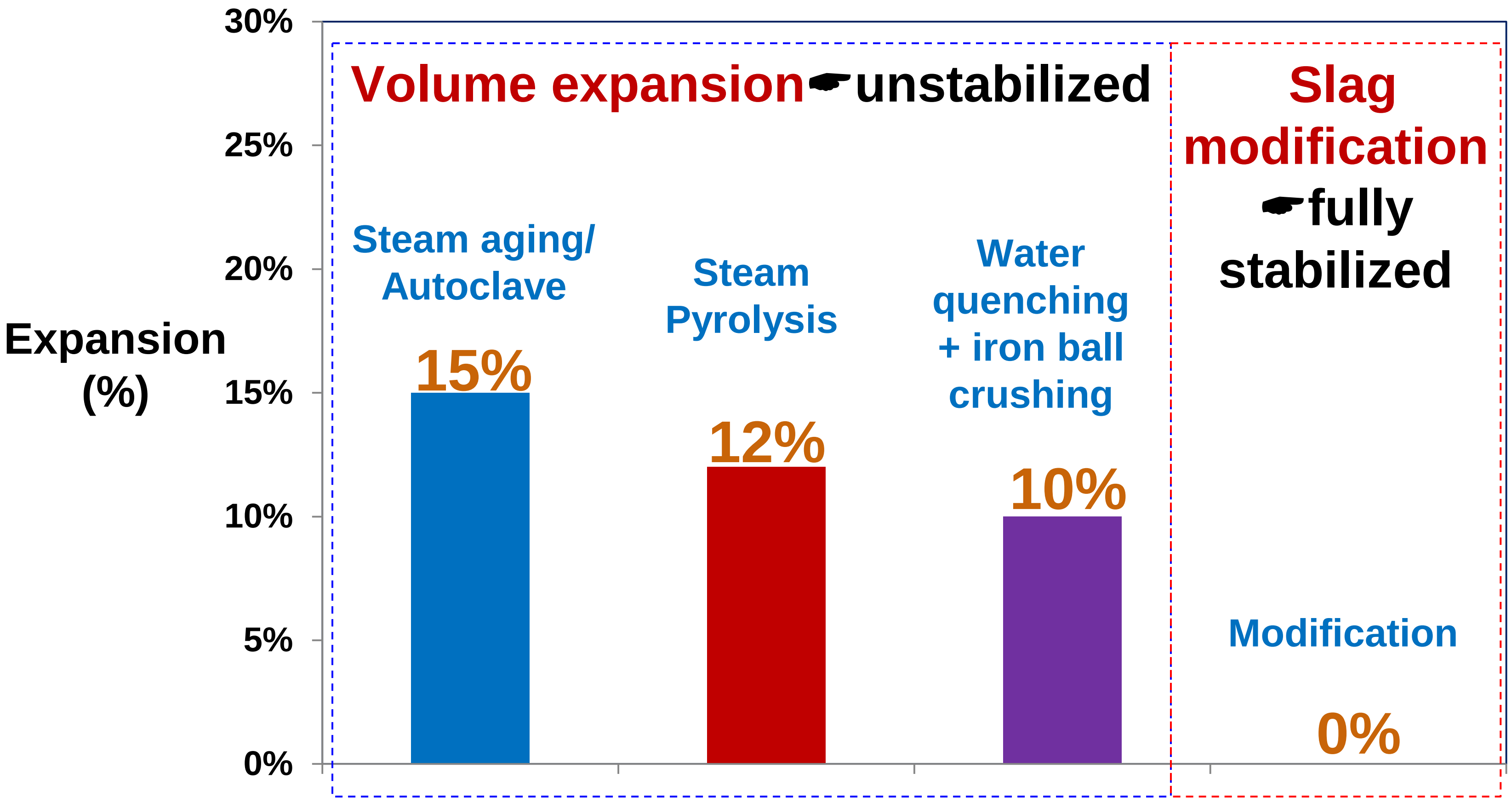
- **Double BOFs operation → reduce specific generation slag**

Steel plants	BOF capacity (Ton)	Type of blowing operation	Unit consumption of lime (kg/ton of crude steel)	Unit consumption of light burned dolomite (kg/ton of crude steel)
Japan	300	Double BOFs	27.6	15.2
China	300	Single slag	37.6	13.1
China	300	double slag	28.3	12.9

worldsteel ASSOCIATION

Develop a fully stable and eco-friendly slag technology

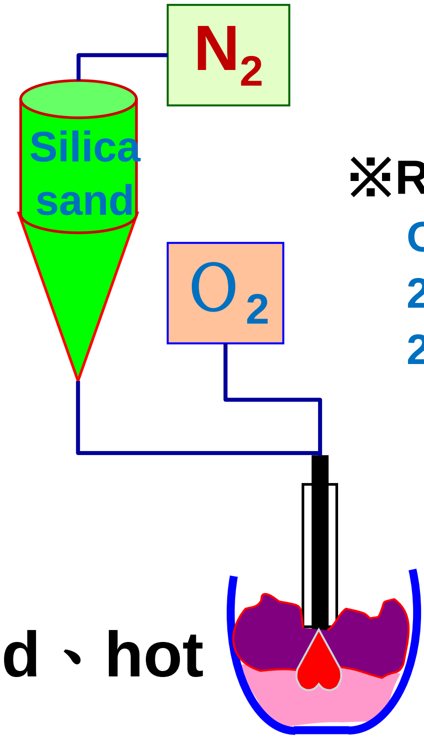
Develop a fully stable and eco-friendly slag technology



Expansion of original slag ~ 20%

Legislative requirement for slag ≤ 0.5%

Hot Stage BOF Slag Modification (HBM) Station



liquid、hot

※Reaction：

$O_2 + 2FeO \rightarrow Fe_2O_3 + \text{energy}$

$2CaO(\text{free}) + SiO_2 \rightarrow 2CaO \cdot SiO_2$

$2CaO(\text{free}) + Fe_2O_3 \rightarrow 2CaO \cdot Fe_2O_3$

BOF--Pouring slag

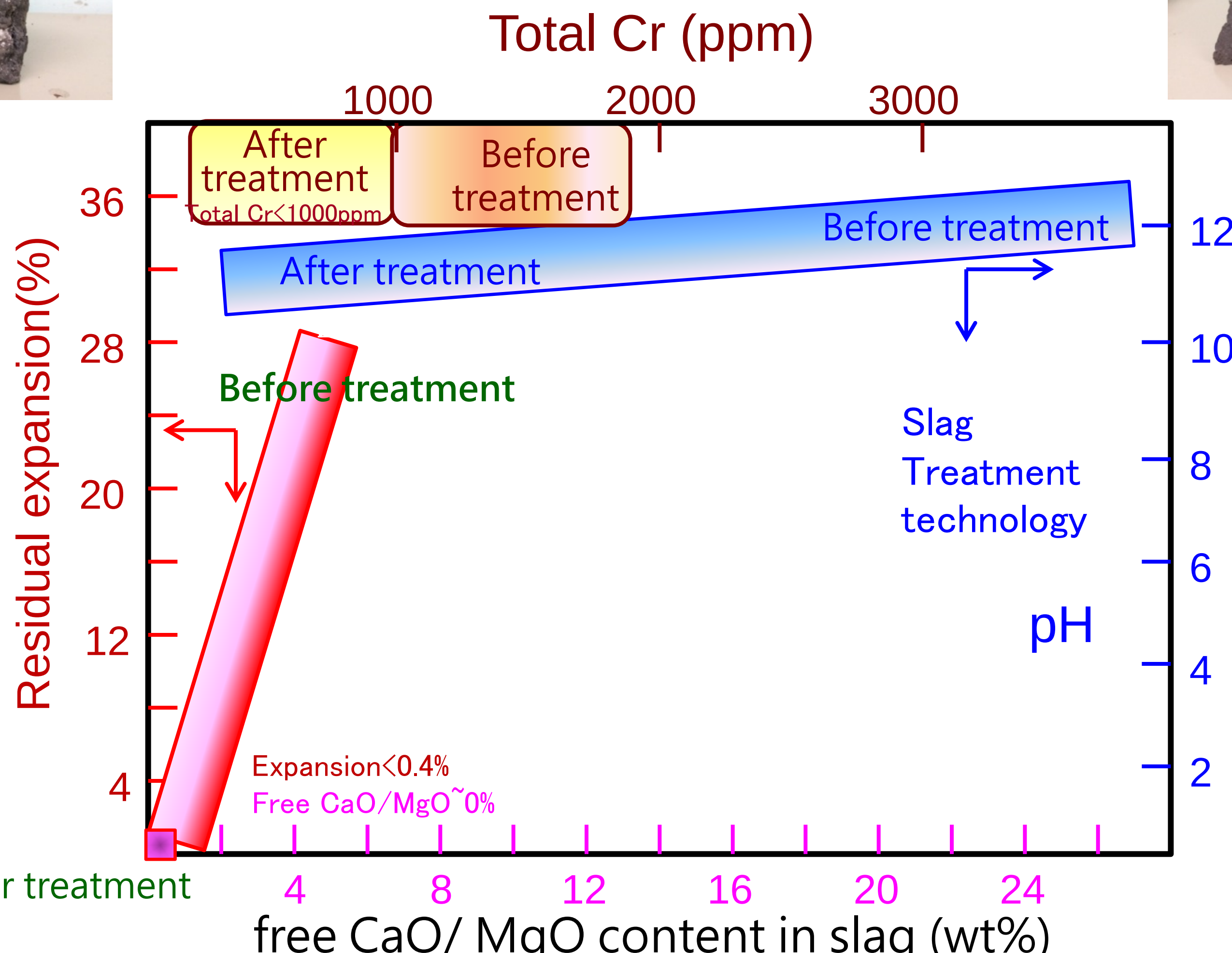
Transportation

HBMs

Modified slag (artificial stone)

Fully stable and Eco-friendly slag (Modified slag/ artificial stone)

disintegration
after hydration



permanent
stable

Make the most of recycling

Make the most of recycling from internal reuse

- **Start reusing from sinter plant (internal recycling)**

  → of course, there must exists De-SOx facility.

- **Advantage**

  If one million (1000,000) tonnes of slag is recycled in sinter plant, then

  ~715,000 tonnes of limestone($CaCO_3$) can be replaced.

  → ~ 10 million € can be saved each year

  ~ 310,000 tonnes of CO_2 emission is eliminated

Legislative position of slag in the circular economy

Legislative position of slag in the circular economy

	Product	By-product	End-of-waste	Waste
De-S slag	Slovakia Taiwan	France-w/h CTPL certificate Korea Sweden Finland India China (north)	--	Brazil China (middle) Turkey, Italy France, Germany UK, Belgium Greece
BOF slag	Belgium Slovakia Taiwan	France-w/h CTPL certificate Austria, Sweden Finland Germany, Netherlands China (north) Korea, India	UK (?)	Brazil China-middle France Turkey Netherlands-rest Italy(Stainless BOFS)
Secondary Refining slag	Italy Taiwan	Belgium Finland	UK(?) Germany(?)	France Greece Netherlands
EAF slag	UK Norway Italy-after treatment	Sweden; Mexico Korea, India Spain, Germany France-w/h CTPL certificate India		Taiwan; Poland France; Brazil Romania China (middle) Japan(Stainless slag)

☛ Promote change in legislation status for slag from waste to a product by making use its superior properties, specific application, and saleable product.

Slag impact on mitigating global climate change

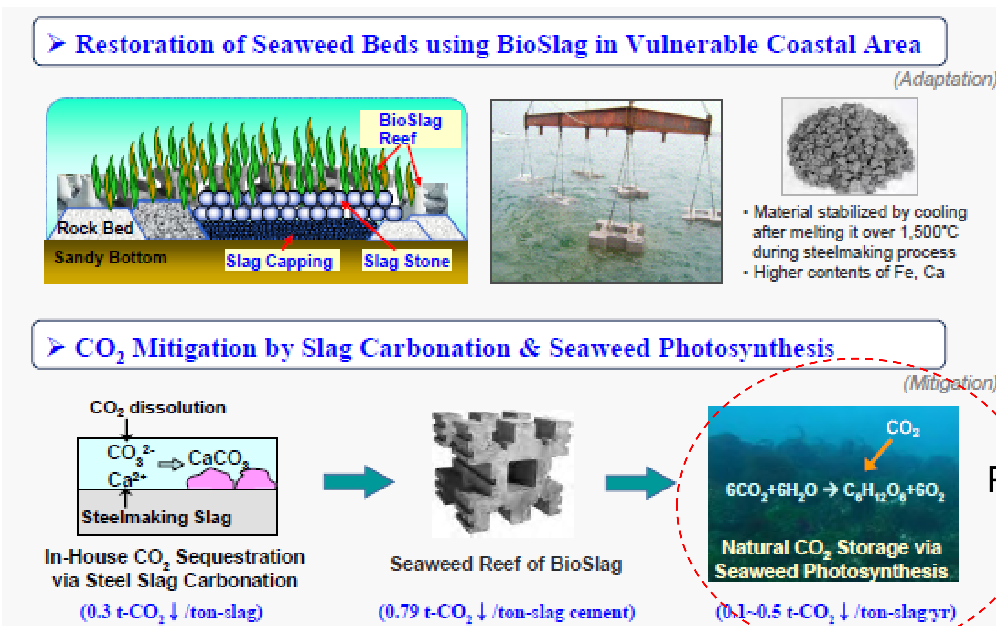
Slag impact on mitigating global climate change

BOF slag → Free CaO/MgO → CO_2 Mineralization → Marine reef

BOF slag → Fe nutrition → Seaweed cultivation → Marine reef

Marine reef ⇒ Marine forest / restoration → Eco-friendly disposal

Marine forest / restoration → CO_2 sequestration



☛ 0.1-0.5 ton CO_2 /ton of slag

☛ Good performance: Japan, Korea (Brazil?)

Ref.: Climate Change Adaptation Using Seaweed Bed of BioSlag in Marine Environment (RIST & POSCO, 2009)(PICES MEQ)

Science Journal-Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions (09, June 2016)

Adding value to slag and turning it into a profitable product

Adding value to slag and turning it into a profitable product

Pavement brick



Concrete products

Building Tile

Asphalt concrete

Ballast - for railway

Thermo-physical properties

Items	Physical properties					(Data from CSC)
	Los Angeles abrasion (%)	Sodium Sulphate corrosion test (%)	Water absorption (%)	Bulk density	Vicker's Hardness(Hv)	Mohr's Hardness
Artificial stone	7.4-10.1 (500 rotation) 18.1 (1000 rotation)	~0.2	0.4-1.2	3.40-3.46	580	~5.5-6.5

Items	Physical Properties		Chemical compositions (wt%) (Data from CSC)							
	True density (g/cm^3)	Los Angeles abrasion (%)	CaO	SiO_2	MnO	MgO	Al_2O_3	TiO_2	Cr_2O_3	others
Artificial stone	3.01	~10.1	30-45	12-22	1.5-3.5	3-8	2-5	0.3-0.7	0.1-0.3	12-28

Items	Specific Heat	Thermal Conductivity	Thermal Diffusivity	P_{25} (Electric resistivity)	Thermal Expansion	Emission Intensity (Electromagnetic wave)	Crushing Strength
Artificial stone	~0.75 J/g°C (23°C) 0.93 J/g°C (300°C)	~1.37 W/mK (23°C) 1.46 W/mK (300°C)	~0.505mm^2/S (1.818x10^{-3}m^2/h) (23°C);0.43mm^2/S (300°C)	~3.54x10^{4}Ωcm	~12.22~12.61x10^{-6} 1/°C(600°C)	>0.90	~204 MPa (2040kg/cm^2)

- A potential thermal energy storage material by its good thermo-physical properties, thermal stability, storage capacity and low price.
- A functional material for health industry by high emission intensity.
- A good waste water treatment agent (even Cr^{+6}) by FexOy content.

Heat recovery and precipitated $CaCO_3$ from slag

☛Hot modified slag is good for heat recovery and producing fine grain for further finish product processing.

Conclusions

Conclusions

- Change the philosophy in steel making and treat slag the same as steel and treat it as a quality product.
- Recycle it internally.
- Develop a stable and eco-friendly slag technology for steel making slag by switching slag to artificial stone, and add value to slag and make it saleable product.
- It converts slag to a resource, saves energy, reduces CO_2 emission, and potentially reduces environmental impact and contributes to protect the environment. It will be a eco-friendly material for the 21 century.
- Promote change in legislation status for slag from waste to a product by making use its superior properties such as electromagnetic characteristics and reducing CO_2 emissions.

Follow-up work

Follow-up work

- Create a steel slag product and process catalogue on Extranet
- Promote the heat recovery from slag
- Promote product catalogue with worldsteel members
- Promote sea reef applications and other product applications
- Promote slag use in cement
- Promote changes to legislation to shift slag from waste to product.
- Promote steel slag as a treatment agent for waste water ($Cr^{+6)}$)
- Promote steel slag as a treatment for weak acid treatment (pH~2).

Thank you for your attention.

For further information contact:

Yu-Chen Andre LEE | Fellow
World Steel Association
lee@worldsteel.org | T: +32 (0)2 708 81 86 | worldsteel.org

worldsteel

ASSOCIATION

worldsteel.org