

# IRON AND STEELMAKING SLAGS: ARE THEY HAZARDOUS WASTE?

BY

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## SYNOPSIS:

Blast furnace slag has been applied for cement making in the early of 1900s. Currently, almost all blast furnace slag is utilized for various purposes, such as cement making, road construction, fertilizer, etc. On the other hand, not all of steel slag is utilized compared to blast furnace slag. The composition of steelmaking slag is dictated by charging material into EAF as well as BOF. For BOF steelmaking route, composition of slag depends on the composition of hot metal and fluxes due to charging of scrap is less than 25%. For most of EAF steelmaking plants, composition of slag is determined by the composition of scrap to be smelted and fluxes. In some EAF steel shops, where sponge iron (DRI/HBI) is charged more than 80%, slag composition is controlled by composition of sponge iron. In some countries, including Indonesia, steelmaking slag is categorized as hazardous and toxic waste. However, slag can be used as raw material for the other purposes. In this paper, the utilization and application of slag as well as slag treatment are reviewed and discussed. In Germany, Japan, USA and some other countries, slag is not classified as hazardous waste. Furthermore, slag shall be treated as resources and not as waste.

**Keywords:** Slag, Steel, Blast Furnace, Hazardous Waste.

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## INTRODUCTION

Slag was used for many applications and its utilisation helps to conserve natural mineral resources and minimises atmospheric emissions<sup>1</sup>. As example, using of iron and steelmaking slags in cement industry to replace limestone and dolomite can enhance financial benefits (fuel saving and increase kiln productivity) as well as reduction of one-third CO<sub>2</sub> emissions for cement making<sup>2</sup>. Therefore, slag shall be considered as environmentally friendly material and used as valuable material for the benefit of mankind. The topic of the conference which was organized by EUROSLAG in 2000 was "slag in the service of mankind"<sup>1</sup>.

At the beginning (1920s), iron and steelmaking slags were classified as hazardous in USA. In 1980, slag was tested by EPA (environmental protection agency) in terms of ignitability, corrosivity, reactivity and toxicity and it was found that iron and steelmaking slags are non-hazardous. The only furnace related by product of steel industry listed as hazardous is electric furnace emission control dust or sludge. Steelmaking slag is an environmentally safe product and has a wide range of uses.<sup>3,4</sup>

In document of “Basel Convention on the Control of Transboundary Movements of Hazardous Waste and Their Disposal”, it was stated that granulated slag arising from the manufacture of iron and steel (B1200, Annex IX, List B) or in general most of slags from metals processing will not considered as “hazardous waste” unless it contains material in Annex I and causing to exhibit characteristic in Annex III<sup>5</sup>. This convention is very general and some countries use this convention as basic for environmental regulation. In case of Indonesia, for safe purpose, steelmaking slag is categorized as hazardous waste. A series of tests shall be conducted as listed in Annex I and Annex III of this convention in order to make sure that slag is not hazardous waste. As stated previously, in the other countries, a lot of researches and tested were conducted to study the slag properties and the influence of slag to the environments. Based on these results, some countries have classified iron and steelmaking slag as non hazardous waste.

## SLAG PRODUCTION

Iron and steelmaking routes are shown in Figure 1. Based on data published by World Steel Association<sup>6</sup>, 1.417 billion tons of steel was produced in the world in 2010. The amount of hot metal (pig iron) is 1.025 billion tons. Based on data published by Genet<sup>7</sup>, slag specific production from blast furnace will reach a plateau around 260-270 kg/t of pig iron. The calculated amount of ironmaking slag which was produced in 2010 is around 271.63 million tons. On the other hand, 1.8 billion tons of cement was produced in 2010<sup>8</sup>. It was clear that blast furnace slag can be used for cement production, which means that if all blast furnace slag is used for cement production in 2010, around 15% of cement raw material come from blast furnace slag. However, in some locations, blast furnace slag production is high compared to the regional cement consumption which means that blast furnace slag might not absorbed locally for cement production.

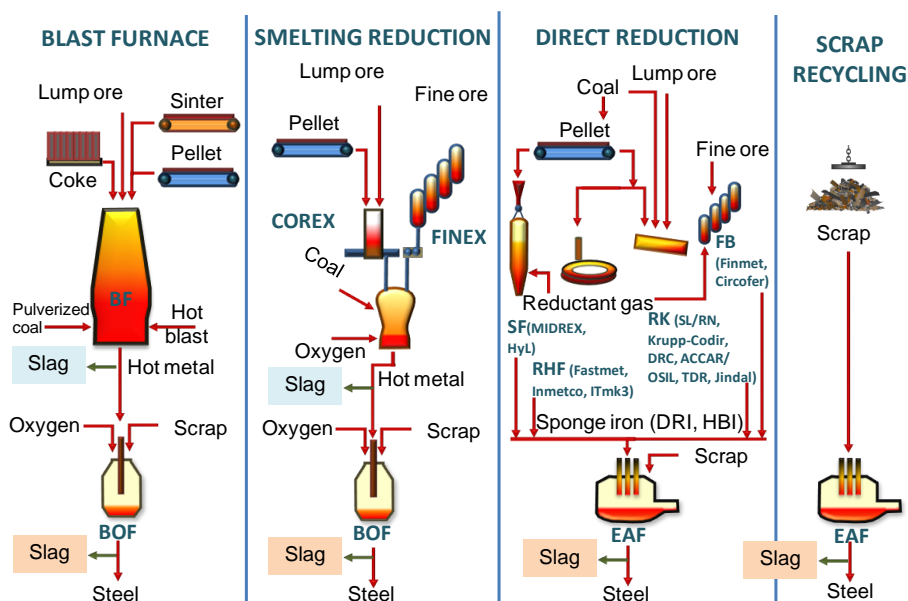


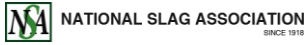






Figure 1: Iron and Steelmaking Route

The amount of steel produced by oxygen converter (BOF) and electric arc furnace (EAF) is 988.592 million tons and 410.726 million tons, respectively. By taking of an average of 12.5% slag is formed during steelmaking, the amount of steelmaking slag produced is 174.91 million tons. The estimation of total iron and steelmaking slags in 2010 is 446 million tons. The amount of slag production will increase continuously inline with the increasing of steel production in the world. These potential slag products shall be treated and beneficiated as resources.

## SLAG ASSOCIATIONS

In order to handle around 400-500 million tons iron and steel slag per year, slag associations in some countries as well as in some regions were established which have focus for manufacturing and utilization aspects of slag as well as to promote slag as product. Some of these associations are listed in Table 1.

Table 1: Associations relating to slag

No	Country/Region	Name of Association	Year founded	Logo
1	USA	National Slag Association (NSA) <sup>9</sup>	1918	
2	Germany	Association of German Portland and Slag Cement Works (Verein Deutscher Portland- und Hüttenzementwerke e.V.) <sup>10</sup>	1948	
3	Germany	Technical Association for Ferrous Slag (Forschungsgemeinschaft Eisenhuetten-schlacke, FEhS) <sup>11</sup>	1968	
4	Japan	Nippon Slag Association <sup>12</sup>	1978	
5	UK	Cementitious Slag Makers Association <sup>13</sup>	1985	
6	Australia	Australasian (iron & steel) Slag Association (ASA) <sup>14</sup>	1990	
7	Canada	Canadian Slag Association <sup>15</sup>		
8	Europe	European Slag Association <sup>16</sup>	2000	
9	USA	Slag Cement Association <sup>17</sup>	2012	

The association conducts regular meeting as well as conference to enables exchange of information and research results, to monitor regulations / standardizations, and to develop product image of slag. One of the examples of this activity is European Slag Conference which was started in 2000<sup>18</sup>. For the case of

South East Asia, slag conference might be the part of “ASEAN Iron and Steel Sustainability Forum” under the umbrella of SEAISI. Or, it could be part of Australasian (iron & steel) Slag Association (ASA).

## UTILIZATION OF IRONMAKING SLAG

The water granulation of blast furnace slag was started in a German blast furnace plant in 1853 and the first German standard for Portland cement with a slag content of 30% was introduced in 1909.<sup>19</sup> The content of blast furnace slag in the cements based on European Standard is shown in Table 2. The application of blast furnace cements shows high resistance against attack from sulphate, sea water, against alkali aggregate reaction, and against the diffusion of chloride into concrete. High performance concrete is achieved by using blast furnace cement.

Table 2: Cement classification and blast furnace slag content <sup>19</sup>

Cement type	Designation	Notation	Blast furnace slag (%-wt.)
CEM II	Portland slag cement	CEM II/A-S	6 – 20
		CEM II/B-S	21 – 35
CEM III	Blast furnace cement	CEM III/A	36 – 65
		CEM III/B	66 – 80
		CEM III/C	81 – 95
CEM V	Composite cement	CEM V-A	18 – 30
		CEM V-B	31 – 50

Steel and cement industries each release an average 5% of the total CO<sub>2</sub> emissions in the world<sup>7</sup>. The reduction of 37% CO<sub>2</sub> can be achieved by using of blast furnace slag cement compared to ordinary portland cement as shown in Table 3. Furthermore, the utilization of blast furnace slag could substitute and save limestone as main raw material for cement production.

Table 3: CO<sub>2</sub> reduction by using blast furnace slag cement<sup>20</sup>

		Ordinary Portland cement	BF slag cement (45% slag)	CO <sub>2</sub> reduction	
				Kg	%
Limestone (kg)		453	278	-175	39
Energy	Fuel (kg)	293	192	-103	34
	Power (kWh)	11	9		
Total CO <sub>2</sub>		757	479	-278	37

The typical blast furnace slag contains 39-42% CaO, 33-39% SiO<sub>2</sub>, 9-13% Al<sub>2</sub>O<sub>3</sub>, 6-9% MgO, 1.2-1.4% S, 0.1-0.5% MnO and 0.4-3.0% TiO<sub>2</sub><sup>21</sup>. This chemical composition is not much different between one blast furnace to the others because most blast furnaces operate within the same chemical constraints. The content of NiO, Cr<sub>2</sub>O<sub>3</sub> and CuO in blast furnace slag can be ignored because the presence of these components in the blast furnace charging material are strictly prohibited and well controlled due to increasing of tramp elements in steel products.

In 2000, 25.6 million tonnes of blast furnace slag was produced in Europe where 66% was used for cement production and 23% as aggregates for road

construction<sup>22</sup>, Figure 2. The slag used for cement production is in the form vitreous slag which is produced by granulation technique while the slag for road construction is the form of crystalline come from slow cooling on air. In 2010, 82% of blast furnace slag was granulated and 18% was air cooled.

The same trend is also shown in Japan in 2010 where 66.6% of blast furnace slag is used for cement production and 22.6% is applied as road construction and concrete/aggregate, Figure 2. 80% of blast furnace slag is in the form water granulated and 20% is air cooled.

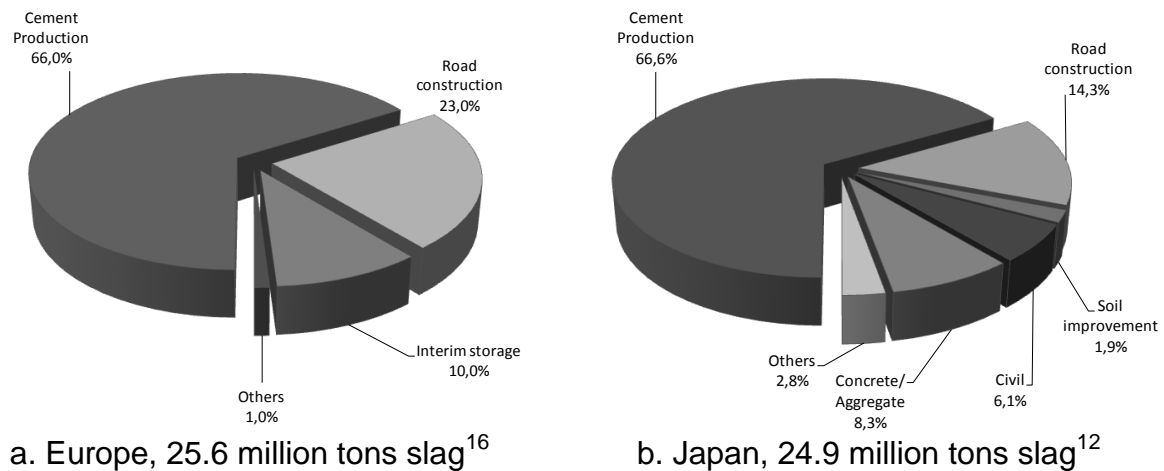


Figure 2: Use of blast furnace slag in Europe and Japan, 2010

The utilisation of blast furnace slag as agricultural liming materials is not only for saving resources but with its numerous positive effects on different parameters of soil fertility it forms a basis for a sustainable agricultural production<sup>23</sup>. The long term using of blast furnace slag as fertilizers or liming materials results benefit for crop yield and soil fertility without providing a risk<sup>24</sup>.

The use of slag plays a role in reduction of the amount of material to be stockpile or dumped in landfills which are potential sources of soil contamination and air pollution<sup>25</sup>. Due to its potential for reuse as raw material or as input for other processes and applications, blast furnace slag is not waste, it is co-product of ironmaking plant which is valued in markets worldwide.

## UTILIZATION OF STEELMAKING SLAG

Steel slag is also known as black slag due to containing of high FeO. The typical composition of EAF and BOF steel slag is shown in Table 4. Based on data published by Euroslag in 2010, around 13% of steel slag is not used for any applications. The slag is dumped as final disposal. This situation is different with blast furnace slag where almost all blast furnace slag is utilized. The main application of steel slag is used for road construction and civil as shown in Figure 3. Less than 7% of steel slag is applied for cement production. In case of Japan, only

2.3% of steel slag is land filled. The rest of steel slag is used for various applications. The utilization of steel slag for constructing of seaweed beds is currently under studied in Japan<sup>26</sup>.

Table 4: Typical composition of steel slag<sup>21</sup>

Wt.%	CaO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	S	Fe as FeO	MnO	P <sub>2</sub> O <sub>5</sub>	Cr as Cr <sub>2</sub> O <sub>3</sub>	Free CaO	CaO/SiO <sub>2</sub>
EAF	30-40	10-20	<10	<10	<0.25	15-35	<10	<2	<2	1.8-2.8	1.8-2.8
BOF	42-52	9-13	0.5-3	1-8	~0.25	15-35	3-10	1.5-4	<2	~4	~4

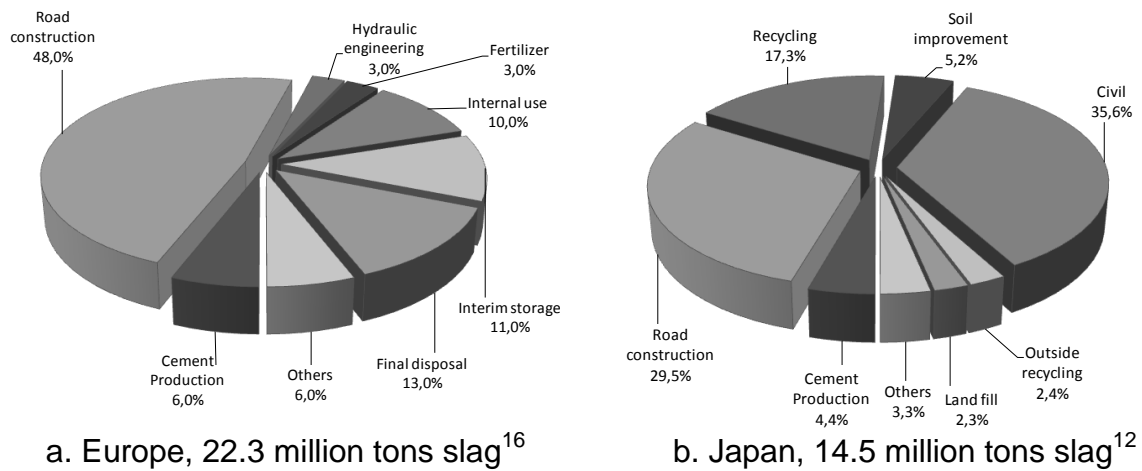


Figure 3: Use of steel slag in Europe and Japan, 2010

The contain of Cr as Cr<sub>2</sub>O<sub>3</sub> in the slag is suspected to be hazard compared to blast furnace slag due to the possibility for the formation of chromium hexavalent. The research of utilization of slag from stainless steel industry containing 2.48-4.28 chromium shows that chromium is stable in the oxide therefore it was concluded that stainless steel slag is regarded as non hazardous waste<sup>27</sup>. Heat treatment and adjusting of slag composition can be used to bind chromium in a stable spinel mineral phase<sup>28</sup>.

In the recent published paper on study of the reuse of steel slag for road applications (aggregates for embankment, road layer, and industrial usable platform), the leaching test showed low chemical release level which is the same as inert materials<sup>29</sup>. Furthermore, it was concluded that concludes black slag of electric arc furnace has great potential for recovery as a by product as a substitute for aggregates in manufacture of mortars, aggregates in embankments, drainage fill material, artificial gravel and concrete and as raw material for the production of clinker in cement facilities<sup>30</sup>.

## UTILIZATION AND APPLICATION OF STEELMAKING SLAG IN INDONESIA

The steel produced in Indonesia is mainly by electric arc furnace and small amount by induction furnace. The amount of slag produced per year is predicted between 300.000 - 400.000 tons. Referred to PP 18 Jo 85 1999, steel slag is categorized as hazardous waste. However, steel slag can be treated as normal waste if TCLP, LD50 and characteristic tests do not indicate hazardous.

At PT Krakatau Steel, slag is transformed into stable structure by rapid cooling method (slag atomizing technology) which is known as precious slag ball (PS ball) which is used for shot blasting, grit, sand paper, roofing granules, non-slip surfaces and filter media for industrial waste water treatments<sup>31</sup>. Due to classification of steel slag by Indonesian government as hazardous material, the utilization of this product might be a problem. The TCLP and LD50 tests for steel slag at PT Krakatau Steel does not contain hazardous component.

EAF - steel slag from PT Ispat Indo has been used for road construction. Currently, the application of steel slag for fertilizer has been studied which showed positive result. The TCLP, LD50, and characteristic tests indicate that steel slag is non toxic and shall not be classified as hazardous waste<sup>32</sup>.

The utilization of laterite ore containing chromium oxide and nickel oxide as source of iron and steelmaking in Indonesia will be soon an issue for the environment. Therefore, researches and bench marking with the other plants/countries shall be conducted.

## SUMMARY

The amount of iron and steel slag produced per year is roughly between 400 – 500 million tons. Therefore slag is a resource and shall be applied for various purposes. In USA, by conducting research together with Environment Protection Agency, since 1980, iron and steel slag is not classified as hazardous waste. This condition is similar to Germany, Japan and some other countries. Iron and steel slag is a by-product or co-product of iron and steelmaking plants which is saleable. In case of Indonesia, steel slag is classified as hazardous waste. More researches shall be conducted between ministerial for environment, industries, research institutes and universities to evaluate the long term of slag influence during its application to the environment and to prove that slag is not hazardous waste. SEAISI shall actively organize meeting between the South East Asia countries for utilization of slag as well to develop standardization and to monitor the regulations for slag utilization.

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