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Environmental factors of utilizing steel slag as building materials and backfill materials

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ABSTRACT

This study aims to present about national and international regulations, standards related to environment parameters when using steel slag as building materials and backfill materials. As a part of this research, environmental tests were undertaken to determine the hazardous components, natural radioactivity and potential of leaching heavy metals of steel slag samples. The laboratory test results shown that steel slag is classified as a non-hazardous industrial waste. In terms of natural radioactivity, steel slags were found to pose no environmental risks for use as building materials and backfill material. Although trace amount of heavy metals was found in steel slag components, leachable heavy metals analysis implied the low possibility of leaching issue for steel slag applications. To give out a comprehensive conclusion on the environment impact of the use of steel slag, further environmental tests under actual conditions need to be performed. However, this initial laboratory test results demonstrated that steel slags have a great potential for use as building materials and backfill material without environmental risks surrounding the area of use.

1. Introduction

Steel slag is an industrial waste that generated during the steelmaking process. According to data from the World Steel Slag Association, total steel slag output was 250 million tons in 2018[1]. The emission of stee slag leads to the formation of large amount of dust that can pollute the air; harmful components such as heavy metals can leach to surface water and ground water. When steel slag cannot be effective reused, its disposal becomes a serious problem for society and industry. Therefore, the reuse of steel slag is not only bringing benefits for environmental protection and economic development, but also contributes greatly to the sustainable development of society.

Currently, utilization of steel slag in the field of construction has been paid much attention in many countries around the world. The utilization rate in Japan, USA and EU countries was 98.7 %, 84 % and 87 %, respectively [1]. The main applications are cement production, embankments, road construction, civil engineering, internal recycling, backfill material and agriculture. In recent years, many researchers have published their researches relevant to application of steel slag as building materials and backfill material. These researches deal not only with engineering properties of steel slag, but also on environmental impacts. In terms of environmental impacts, these studies are mainly concerned about evaluation of toxic components, radioactive properties and leaching ability of heavy metals in steel slag to environment before being use [2-4].

In Vietnam, based on the present steelmaking technology, there are three types of steel slag: basic oxygen furnace slag (BOF slag), electric arc furnace slag (EAF slag) and induction furnace slag (IF slag). According to Vietnam Steel Slag Association, the estimation of total amount of steel slag was about 7 million tons in 2020. Despite their large amount of generation, steel slag is still considered as industrial solid waste with some hazardous properties and needs to be treated and buried [5]. Recently, the practical use of steel slag as construction and backfill material in Vietnam is also increasing diversity and abundant, mainly as concrete aggregates, road base and subbase materials and backfill material [6-9]. However, the actual utilization rate is very small compared to the amount of steel slag generated annually. This is mainly due to the fact that the steel slag contains trace amounts of toxic elements that have leaching potential to environment. On the other hand, limited studies on the environmental impacts in term of application have been reported to date. This is also a major reason for low utilization rate of steel slag in Vietnam compared to other countries.

In order to promote the practical use of steel slag and clarify environmental issues related to the reuse of steel slag in construction field, in this research, an overview on regulations related to environmental risks was given out and environmental laboratory investigations were carried out to assess the viability of using these steel slag as this aspect has not yet to be studied in Vietnam to date.

2. Overview of environmetal regulations

In general, the published researches, regulations and standards on using steel slag as construction materials and backfill material in the world focus on the following main issues:

- Determination of hazardous components in steel slag
- Radioactive properties of steel slag

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- Leaching ability of heavy metals into the environment surrounding area of use.

2.1. Hazardous identification in steel slag

In most countries around the world, before being used, steel slag needs to be categorized as hazardous or non-hazardous industrial solid waste.

According to United States Environmental Protection Agency (EPA), an industrial waste is considered as hazardous when it has certain properties such as flammability, corrosivity, reactivity, and toxicity. Therefore, to assess the environmental impact when using steel slag in geotechnical applications, environmental tests should be performed. According to EPA 2010, tests for hazardous components should be performed first to assess the hazardous properties of steel slag. The obtained results will be compared with the thresholds specified for inert waste and backfilling materials issued by the EPA. If the all total concentration test is below the specified limit, steel slag is classified as non-hazardous waste and can be reused in suitable applications [10].

In Indiana [11], the use of steel slag is regulated by the solid waste land disposal regulation. Accordingly, solid waste is classified based on the concentrations of various metals in their leachates. The required extraction tests were Toxicity Characteristic Leaching Procedure – TCLP (acid leachate) and Neutral Leaching Method – EP (neutral leachate). Here, four solid waste types are classified from type I to type IV based on TCLP test results. Test results show that both BOF and EAF slag are classified as type III – normal solid waste. Because the chemical composition of steel slag varies according to steelmaking technology and the input raw materials, TCLP tests are performed regularly for the purpose of steel slag classification. The criteria and thresholds for classification are shown in the Table 1.

Table 1. Indiana restricted waste criteria based on TCLP tests.

Test item	Concentration (mg/l)			
	Type IV	Type III	Type II	Type I
As	≤0,05	≤0,5	≤1,25	≤5
Ba	≤1,9	≤10,0	≤25	100
Cd	≤0,01	≤10	≤0,25	<1
Cr	≤0,05	≤0,5	≤1,25	<5
Pb	≤0,05	≤0,5	≤1,3	<5
Hg	≤0,002	≤0,02	≤0,05	<0,2
Se	≤0,08	≤0,1	≤0,25	<1
Ag	≤0,05	≤0,5	≤1,25	<5

In EU countries [12], steel slag when stored in landfills is subject to the requirements of the Landfill Directive (1999/31/EC) to minimize environmental impacts. This Directive specifies requirements that hazardous waste, non-hazardous waste and inert waste need to be handled separately from each other. When the analyzed result of concentration of heavy metals according to the current standards of steel slag do not exceed the allowable threshold, slag from the steelmaking industry is not hazardous waste and is classified as inert solid waste.

In Vietnam, the Ministry of Natural Resources and Environment has issued QCVN 07: 2009/BTNMT–National technical regulation on hazardous waste thresholds [13]. This regulation specifies the concentration threshold of hazardous components to classify an industrial waste as normal waste or hazardous waste. In this regulation, a waste is classified as non-hazardous waste if all hazardous properties or components do not exceed the hazardous waste threshold stated in the regulation. In addition, according to Appendix C–List of hazardous wastes promulgated together with Circular 36/2015/TT-BTNMT, waste from iron and steel factories is classified as hazardous waste with code 05 01–Waste from the iron and steel industry and code 05 11–Sludge and solid waste from the smelting process. To ensure that steel slag material is not on the list of hazardous wastes, before being used, samples of steel slag must be analyzed and checked for possible inorganic hazardous components according to the prescribed method and compare with the threshold specified in QCVN 07:2009/BTNMT.

2.2. Radioactivity of steel slag

Similar to other types of building material, it is necessary to check the natural radioactivity of steel slag before using as building materials and backfill material. However, limited studies on the natural radioactivity properties of steel slag are the main obstacle for their application in construction works to date.

The literature [14] reported that the most frequently present radionuclides in steel slag are ^{137}Cs, ^{60}Co, ^{226}Ra, ^{192}Ir, ^{241}Am, ^{132}Th and ^{90}Sr. The increased level of these components will lead to radioactive poisoning for workers and general population. According to Radiation Protection Document 112 of the European Commission, the limited value of activity concentration is 0,5 mSv/y when using blast furnace slag for Portland cement production. Similarly, limited value for bricks made of steel slag or some insulating materials in residential buildings is 20 mSv/y.

The authors [3] conducted a study on the natural radioactivity of EAF slag in Croatia using gamma spectrometer. This research pointed out that in the EAF slag, the presence of natural isotopes such as ^{40}K, ^{232}Th (^{228}Ra), ^{226}Ra and ^{238}U was established. The results were presented in Table 3.

Table 2. Natural radioactivity of EAF slag in Croatia.

Radionuclide	Sample A	Sample B	Sample C
^{40}K (Bq/Kq)	36.9 ± 4.8	15.3 ± 6.1	25.7 ± 5.6
^{226}Ra (Bq/Kq)	17.1 ± 1.9	17.7 ± 2.1	14.6 ± 2.3
^{232}Th (^{228}Ra) (Bq/Kq)	9.8 ± 1.4	6.7 ± 1.9	13.1 ± 2.2
^{238}U (Bq/Kq)	17.3 ± 3.8	15.6 ± 4.3	14.6 ± 3.9

Also the investigation of the presence of the natural isotopes such as ^{40}K, ^{232}Th (^{228}Ra), ^{226}Ra and ^{137}Cs of steel slag in Khartoum area, Sudan was carried out [15]. The specific results were shown in Table 4.

Table 3. Results of activity concentration of natural radionuclide of slag sample in Khartoum, Sudan

Radionuclide	Activity concentration of slag sample	Activity concentration of surrounding soil
^{40}K (Bq/Kq)	321 ± 3	185 ± 3
^{226}Ra (Bq/Kq)	15.2 ± 4	12.6±7
^{232}Th (^{228}Ra) (Bq/Kq)	20.6 ± 5	12.0 ± 5
^{137}Cs (Bq/Kq)	3.33 ± 7	-

Currently, the specific standards and regulations for evaluation of natural radioactivity of steel slag before using as building materials and backfill material are not available. Instead, the evaluation standards for natural radioactivity of building materials are applied to determine the safety level of steel slag before being used in construction field.

All construction materials contain trace amounts of natural radionuclides such as ^{40}K, ^{232}Th (^{228}Ra), ^{226}Ra and ^{238}U. In order to compare the radioactivity of different building materials, a common index that reflects their combined natural radioactivity should be used. This general index is called "the safety radioactivity index" or "the activity concentration index" of building materials.

In EU countries, the required radioactivity index I for materials used with large volume will not exceed 1 and materials used in small quantities will not exceed 6.

Table 4. Radioactivity index and maximum permissible of radioactive elements in building materials intended for use in road construction in EU countries [16].

Country	Radioactivity index (Bq/kg)	Limited value	Maximum permissible concentration (Bq/kg)
Germany	—	—	$C_{Ra} = 200$
Finland	$I = \frac{C_{Ra}}{700} + \frac{C_{Th}}{500} + \frac{C_K}{8000} + \frac{C_{Cs}}{5000}$	I<1	—
Latvia	$I = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200}$	I<1	$C_K < 2500$
Lithuania	$I = \frac{C_{Ra}}{700} + \frac{C_{Th}}{500} + \frac{C_K}{8000}$	I<1	—
Norway	$I = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$	I<1	$C_{Ra} < 200$
Poland	$I = 0,0027C_{Ra} + 0,0043C_{Th} + 0,00027C_K$	I<1	$C_{Ra} < 185$
Luxembourg	—	—	$C_{Ra} < 350$ $C_K < 5000$ $C_{Th} < 250$
Croatia	$I = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$	I<1	$C_{Ra} < 200$ $C_K < 300$ $C_{Th} < 200$

In Russian, standard named "GOST 30108– Building materials and elements. Determination of specific activity of natural radioactive nuclei" prescribes the method of determining the radioactive activity of building materials and the field of use depending on their radioactive level [17]. Table 6 shown the scope of application for construction materials in accordance with this standard.

In Finland, standard named "STUK ST 12.2/2010 – The Radioactivity of building materials and ash", presents the action levels related to limiting gamma radiation exposure caused by materials used in building contractions, roads, street or in related building works, or by materials used in mounding, landfill or landscaping [18]. The radioactivity index and the required level in this standard are specified in Table 7. Based on the author's knowledge, this standard is considered to be a comprehensive standard in terms of radioactivity of building materials.

Table 5. Scope of application for construction materials in accordance with GOST 30108.

Aeff value Bq/kg	Classification of material	Scope of application
Aeff< 370	I	Used for all applications
370 ≤ Aeff ≤ 740	II	Road construction, residential buildings and industrial buildings
740 ≤ Aeff≤ 2800	III	Road construction for non-residential area
Aeff > 2800	IV	Use with permission

Table 6. Limited levels and scope of application in accordance with STUK ST 12.2/2010.

No.	Application areas	Required level in STUK ST 12.2/2010		Scope of application
1	Materials used in in building construction, I_1	Clause 3.1 $I_1 \le 1$	$I_1 = \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_K}{3000}$	The material can be used as building material without restriction
		Clause 3.1 $I_1 \le 6$		The material can be used as surface materials and other materials with a minor use in building construction (such as thin tiles)
2	Materials used in road, street and related construction work, I_2	Clause 3.2 $I_2 \le 1$	$I_2 = \frac{C_{Th}}{500} + \frac{C_{Ra}}{700} + \frac{C_K}{8000} + \frac{C_{Cs}}{2000}$	The material can be used in road, street and related construction work without restriction
		Clause 3.2 $I_2 \le 1.5$		The material with a restricted use (such as usual paving stones or paving tiles)
3	Materials used in mounding, landfill and landscaping, I_3	Clause 3.3 $I_3 \le 1$	$I_3 = \frac{C_{Th}}{1500} + \frac{C_{Ra}}{2000} + \frac{C_K}{20000} + \frac{C_{Cs}}{5000}$	The material can be used in in mounding, landfill and landscaping without restriction
4	Handling of ash, I_4	Clause 3.4 $I_4 \le 1$	$I_4 = \frac{C_{Th}}{3000} + \frac{C_{Ra}}{4000} + \frac{C_K}{50000} + \frac{C_{Cs}}{10000}$	Handling of ash in accordance with industrial waste regulations or for disposing of the ash in a controlled landfill site
		Clause 3.4 $I_4 > 1$		The protection of workers involved in ash handling shall be dealt with as laid down in safety in radiation practices

Table 7. Requirements for radioactivity index of building materials in accordance with TCXDVN 397:2007.

No.	Application areas	Calculation formula	Levels of safety
1	Used in building construction		
1.1	High Volume Construction Materials and Products used in building construction	$I_1 = \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_K}{3000}$	$I_1 \le 1$
1.2	Materials used in backfill the floor and the landfill near the buildings		
1.3	Materials used in building construction with a restricted use (such as usual paving stones or paving tiles)		$I_1 \le 6$
2	Used in construction of outside buildings		
2.1	High volume construction materials used in the construction of traffic and irrigation works	$I_2 = \frac{C_{Th}}{500} + \frac{C_{Ra}}{700} + \frac{C_K}{8000}$	$I_2 \le 1$
2.2	The material with a restricted use (such as usual paving stones or paving tiles)		$I_2 \le 1.5$
3	Used in landfill		
3.1	Materials used in landfill without item 1	$I_3 = \frac{C_{Th}}{1500} + \frac{C_{Ra}}{2000} + \frac{C_K}{20000}$	$I_3 \le 1$
3.2	Materials don't used in landfill, need to be stored		$I_3 > 1$

In Vietnam, standard name "TCXDVN 397:2007– Natural radioactive activity of building materials - Safety level in use and test methods" has been issued by the Ministry of Construction under Decision No. 24/2007/QĐ-BXD in 2007. This standard, however, is pending to be converted into TCVN according to Article 7 of Decree 127/2007/ND-CP – Guideline for the Law on Standards and Technical Regulations [19]. In this standard, radioactivity index of all materials used in contractions, ground backfill purposes, and materials for traffic works (outside of the house) must be not exceed 1 ($I < 1$). For the detail information, see Table 8.

2.3. Leaching ability of heavy metals to environment

Although many studies and regulations indicated that steel slag is not a hazardous waste, is radioactively safe and has suitable mechanical properties as construction materials, backfill material. However, steel slag is still not widely used with large amount to date because it is well-known fact that steel slag contains trace amount of potentially toxic elements which may releases into the ground water and surface water surrounding the area of use. In addition, the pH value is also affected by pH of used steel slag. Therefore, environmental investigation should be performed to point out appropriate control measures.

Regulation No. 22, Section 22. 1102 of the Arkansas Pollution Control and Ecology Commission specifies that requirments for site characterization for non-hazardous industrial waste are dependent on the potential for the waste to impact surface water and ground water quality as determined by ASTM D 3987 (1985)– Standard test method for shake extraction of solid waste with water [20]. The leaching test results are to be compared with surface water and groundwater standards applicable to each specific area.

Illinois Administrative Code Title 35 Part 817 also specifies requirements for landfills of waste generated by the steel industry [11]. Section 817.103 states that for steel slag to be buried or reused, it should be tested according to ASTM D 3987-85 to determine the components and concentrations of leachate. Extraction test results are also to be compared with current regulations on surface and ground water quality.

"Guideline 11" issured by the North Dakota Department of Health specifies information that should be carried out in a proposal for beneficial reuse of ash [11]. Along with required information such as source, quality, proposed use of ash, the guideline specifies that it is necessary to perform the leach analysis of ash and a laboratory simulation of the environment properties of the proposed use. Method for leaching test should be either EPA SPLP – Synthetic Precipitation Leaching Proceduce or ASTM D 3987.

In Japan, steel slag applicable to building materials, road construction and backfill material must be checked for environmental criteria before being used, as showed in Table 9 [21-23]. Specifically, the standard "JIS A 5015:2018 - Iron and steel slag for road construction" specifies environmental criteria and permissible limits when using steel slag for road construction. On the other hand, "JIS A 5011-4:2018 – Slag aggregate for concrete – Part 4: Electric arc furnace oxidizing slag aggregate" specifies environmental criteria and permissible limits when using EAF slag as concrete aggregate applications.

In Vietnam, the researches and tests to assess leaching ability of heavy metal in steel slag into the surrounding environment has not been focused. Currently, there are no published studies on the leakage of heavy metals when using as building materials and backfill material. In the "Guideline on iron slag and steel slag use as building materials" issued under Decision No. 430/QD-BXD, however, environmental aspects were mentioned [24]. For the detail information, see Table 10. In fact, the regulations and national standards promulgated related to the use of steel slag are still incomplete. In order to promote the use of steel slag in construction works, more studies and comprehensive assessment of the possibility of heavy metal leakage are required. These researches also provide the basic information for state management agencies to develop more standards related to utilization of steel slag in the field of construction.

Table 8. Permissible values for environmental safety for utilization of steel slag in Japan.

No.	Test item	Steel slag for road construction JIS A 5015:2018		EAF slag for concrete aggregate JIS A 5011-4:2018	
		Limited value for elution level (mg/l)	Limited value for acid extractable content (mg/kg)	Limited value for elution level (mg/l)	Limited value for acid extractable content (mg/kg)
1	Cd	0.01	150	0.01	150
2	Pb	0.01	150	0.01	150
3	Bo	1	4000	0.05	250
4	As	0.01	150	0.01	150
5	Hg	0.0005	15	0.0005	15
6	Se	0.01	150	0.01	150
7	F	1.00	4000	0.8	4000
8	Cr (VI)	0.05	250	1	4000

Table 9. Environmental regulation of steel slag applications in Vietnam in accordance with Decision No. 430/QĐ-BXD.

Scope of application	Test item	Applied standards
Materials for road construction	Emission of harmful substances	JIS A 5015:2018
Materials for backfilling, inserting textures…	pH value of leaching fluid Emission of harmful substances	Not mention

3. Results for evaluation of environmental impact in laboratory

3.1. Impact of hazardous components in steel slag

In this study, some samples of steel slag including EAF, BOF and IF slag were analyzed for hazardous components according to the methods specified in QCVN07:2009/BTNMT. The analyzed results in Table 11 shown that the total concentrations of hazardous substances content in all steel slag samples meet the requirements set out in QCVN 07:2009/BTNMT. From this result, it can be concluded that all tested steel slag in Vietnam are not a hazardous waste at all. Instead, these tested steel slag samples are considered as normal solid waste and can be used like other common industrial wastes in suitable applications.

Table 10. Results of hazardous identification of steel slag in Vietnam.

Test item	Limited value of total concentration in QCVN 07:2009/BTNMT	Unit	BOF slag	EAF slag	IF slag
Sb	20	ppm	<0.05	0.83	0.34
As	40	ppm	<0.05	<0.5	<0.5
Ba	2000	ppm	<0.05	2.09	0.19
Ag	100	ppm	<0.05	<0.5	<0.5
Be	2	ppm	<0.05	<0.05	<0.05
Cd	10	ppm	<0.05	<0.5	<0.5
Pb	300	ppm	<0.05	<0.5	<0.5
Co	1600	ppm	<0.05	<0.5	<0.5
Zn	5000	ppm	<0.05	<0.5	<0.5
Mo	7000	ppm	0.096	<0.5	<0.5
Ni	1400	ppm	<0.05	<1.0	<1.0
Se	20	ppm	<0.05	<0.5	<0.5
Ta	140	ppm	<0.05	<1.0	<1.0
Hg	4	ppm	<0.05	<0.02	<0.02
Cr(VI)	100	ppm	<0.05	<2.0	<2.0
Va	500	ppm	12.54	<0.5	<0.5
Flo	3600	ppm	77	<0.002	<0.002
Total CN^-	590	ppm	2.59	<0.1	<0.1
pH	2~12.5	-	12.39	11.3	10.6
BOF slag from Hoa Phat Dung Quat steel		EAF slag from Vina Kyoei steel		IF slag from Viet Nhat steel	

3.2. Impact of radioactivity of steel slag

Based on the natural radioactivity measured from the steel slag samples, the radiation safety criteria of these steel slag samples were calculated according to Dutch standards STUK ST 12.2/2010 and TCXDVN 397:2007. The results in Table 12 shown that the radioactivity index I of all tested steel slag samples is less than 1. This result meets the requirements specified by the two standards mentioned above. From this result, it can be concluded that all collected steel slag in this project can completely be used as building materials, backfill materials without radioactive influence on the application environment.

Table 11. Results of radioactivity index of steel slag in Vietnam.

Evaluation standard			EAF slag	BOF slag	IF slag
Activity concentration	^{226}Ra		18.9	41.2	20.9
	^{232}Th		18.2	8.84	10.7
	^{40}K		0	0	32.8
	^{137}Cs		0	0	0
STUK ST 12.2/2010	Materials used in building construction.	$I_1 \leq 1$	0.15	0.18	0.13
	Materials used in road. street and related construction works.	$I_2 \leq 1$	0.06	0.08	0.06
	Materials used in mounding. landfill and landscaping.	$I_3 \leq 1$	0.02	0.03	0.02
	Ash handing.	$I_4 \leq 1$	0.01	0.01	0.01
TCXDVN 397:2007	Materials use in building construction.	$I_1 \leq 1$	0.15	0.18	0.13
	Materials used in outside of buildings.	$I_2 \leq 6$	0.06	0.08	0.06
	Fill materials.	$I_3 \leq 1$	0.02	0.03	0.02

3.3. Impact of leaching of heavy metals to environment

To evaluate the possibility of heavy metal leakage into the environment when using steel slag, three samples of steel slag were tested to determine the environmental criteria specified in the standard JIS A 5015:2018 – Iron and steel slag for road construction. The results were presented in Table 13. These results shown that all tested slag samples have met the requirments of JIS A 5018:2018. From this, it can be concluded that the use of steel slag for road construction does not have a significant environment impact.

Table 12. Results of environmental tests in accordance with JIS A 5015:2018

No.	Test item	Leaching concentration, mg/l				Extractable content, mg/Kg			
		BOF slag	IF slag	EAF slag	Limited value in JIS A 5015	BOF slag	IF slag	EAF slag	Limited value in JIS A 5015
1	Cd	<0.0001	<0.0001	<0.0001	0.01	<0.05	0.38	0.23	150
2	Pb	<0.0001	0.0002	0.0003	0.001	1.30	37.99	1.44	150
3	Bo	0.0008	0.0030	0.0028	0.001	2.08	2.21	1.88	150
4	As	0.0003	0.0003	0.0005	0.0005	0.55	0.06	0.15	15
5	Hg	0.0042	0.0007	0.0020	0.01	0.12	<0.05	0.37	150
6	Se	0.1131	0.8116	0.7055	1	89.62	157.46	272.22	4000
7	F	0.24	0.54	0.22	0.8	436.67	213.33	256.67	4000
8	Cr (VI)	<0.0001	<0.0001	<0.0001	0.05	<0.05	<0.05	<0.05	250

Table 13. Results of leaching test of steel slag in accordance with ASTM 3987.

No.	Test item	Unit	Allowable value in QCVN 40:2011/BTNMT (Column B)	Results		
				EAF	BOF	IF
1	pH	-	5.5 ~ 9	11.2	12.2	11.2
2	TSS	mg/l	100	19	125	18
3	Cl^-	mg/l	1000	0.36	0.63	0.43
4	F^-	mg/l	100	0.09	0.73	0.47
5	Mn	mg/l	1	<0.5	<0.5	<0.5
6	Fe	mg/l	5	<0.01	0.1	<0.01
7	Cu	mg/l	2	<0.01	<0.01	<0.01
8	Cr (VI)	mg/l	0.1	<0.05	<0.05	<0.05
9	Zn	mg/l	3	<0.005	<0.01	<0.005
10	Ni	mg/l	0.5	<0.001	0.002	<0.001
11	As	mg/l	0.1	<0.001	<0.001	<0.001
12	Cd	mg/l	0.1	<0.001	<0.001	<0.001
13	Pb	mg/l	0.5	<0.001	<0.001	<0.001
14	Hg	mg/l	0.01	<0.0002	<0.0002	<0.0002
15	CN^-	mg/l	0.1	<0.002	<0.01	<0.002

To evaluate the possibility of heavy metal leakage into the environment when used as a backfill material, leaching tests were performed according to ASTM D 3987-85. As noted above, ASTM D 3987–85 is a water-shake method, used to obtain leachate of solid waste rapidly. This analysis result can be used to estimate the release of hazardous components to the environment based on laboratory conditions specified by EPA. The leachable concentration results for three kinds of steel slag according to ASTM D 3987-85 were shown in Table 14. This results indicated that except for pH value exceeding the threshold, the remaining criteria are below the threshold specified by QCVN 40:201/BTNMT–National technical regulation on industrial wastewater – Column B: Pollution parameters of industrial wastewater when it is discharged into water sources not serving tap water supply [25]. The high pH value in the extract solution is explained by the fact that the pH of steel slag is usually in the range of 10-12, which is higher than that of common buidling materials. However, published studies in the world have shown that the pH value will gradually decrease with time of use and this parameter should be strictly controlled. The pH value can be adjusted by using steel slag in combination with other backfill materials in suitable proportions. In addition, for EAF and IF slag, fluorine and chloride were detected; for BOF slag, fluorine, iron and nickel were detected. Although these detected criteria were lower than the threshold specified in QCVN 40:2011/BTNMT, it is necessary to conduct more researches on environment tests in reality application when using these type of slag with large volume.

The result of laboratory tests of steel slag samples implies no environmental risks or leaching issue for their contruction applications. In order to make the final conclusions, however, more research relavant to environmental concerns need to be done, not only in the laboratory but also in reality.

4. Conclusions

Results on environmental tests of three typical steel slag samples in the laboratory provide a platform for evaluating the possibility of using these wastes in road construction and engineering backfill applications. The result of hazardous identification implies that steel slag is not a hazardous waste, it is a normal solid waste and can be completely reused in suitable applications. In terms of radioactivity, steel slag fully meets the current requirements for building material applications and can be used in large volume without the potential risk of radioactivity. Although trace amount of heavy metals presents in steel slag, however, comparison between leaching ability results and limited values in QCVN 40:2011/BTNMT indicates that all contaminants entirely lie within allowable limits. The pH value is a factor that needs to be further studied to provide appropriate control measures before being used.

Although it is necessary to conduct more studies in this field, it is pertly obvious that steel slag can be promising replacements for natural resources used in construction field. This research is also a useful reference source for father studies related to the reuse of other types of waste with similar properties in the construction applications and other applications.

5. References

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