

Application and Prospect of Ferrous Slag, Coal Combustion By-products

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Abstract :

Recycling of Ferrous Slag(FS), Coal Combustion By-products(CCBs)is encouraged in many countries around the world. However, it is difficult to improve the recycling rate due to the lack of new bulk recycling methods. In this paper, the case study was conducted about usage of FSand CCBs in concrete block pavement and permeable concrete pavement fields. In addition, the availability and prospect of FS and CCBs in the field of concrete block pavement are discussed. FS was shown to be useful as concrete block aggregate. Especially, Steelmaking Slag(SS) was found to be advantageous in terms of strength and abrasion resistance when used as concrete block aggregates [1]. However, in the case of Basic Oxygen Furnace(BOF) slag, it is necessary to thoroughly perform quality control because it needs to be thoroughly pre-treated due to quicklime components. Among the CCBs, with respect to Fly Ash(FA), it is expected that synergy will be achieved in the field of concrete block pavement in conjunction with recent researches on lightweight aggregatesand permeable concrete. Bottom Ash(BA) is becoming increasingly important as an embankment, drainage layer, road base/subbase aggregates. In the field of concrete block pavement, water retentivity performance ofconcrete block using BA has been studied [2]. Therefore, it is expected to increase the usability as a block coarse aggregates.

Key Words : Ferrous slag; Coal combustion by-product; Recycling; Permeable concrete; Concrete block pavement

1. Classification and Characteristics of Materials

Ferrous Slag(FS) is comprised of Blast Furnace Slag(BFS) and the Steelmaking Slag(SS). BFS is produced in the process for producing molten iron in a furnace, and composited of granulated BFS, air-cooled BFS by cooling methods. In Korea, about 80% of ferrous slag is treated with granulated slag. SS is produced in steel refining process, and includes Basic Oxygen Furnace slag (BOF slag) and Electric Furnace Slag (EAF slag). SS undergoes pretreatment such as cooling, crushing, magnetic force sorting, and particle size separation, and is treated being used to roadbed, cement, steel materials and so on. Particularly, EAF slag has high density and high abrasion resistance due to high iron content and is recycled as roadbed material, ascon aggregate and so on.

Most of Coal Combustion By-products(CCBs) are generated in the form of Fly Ash(FA) and Bottom Ash(BA). FA is collected by a dust collector in the process of burning pulverized coal, accounting for about 80% of the CCBs. FA is mainly used as a concrete admixture because it

hasa property of curing by combining with lime easily in the presence of water. BA is generated by a non-combustible components falling in the furnace wall or floor hopper due to coal combustion. The recycling rate of BA has been lower than that of FA, but with the development of recycling technology, the use of concrete aggregate, road base/subbase material is gradually increasing.

2. Recycling Status of Materials

In this chapter, production and recycling practices of FS and CCBs from around the world have been reviewed. In addition, the state of recycling of each country according to the material was investigated and described.

2.1 Ferrous Slag (FS)

Annual FS production in Australia, Europe, South Korea, and the United States is shown in the Table 1.

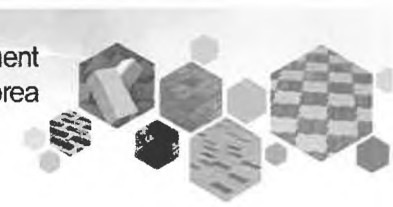
Table 1. Annual production of FS

Country	Year	Blast Furnace Slag (Mt)			Steelmaking Slag (Mt)			
		Granulated	Air-cooled	total	BOF	EAF	Others	Total
Australia[3]	2002	1.1	0.7	1.8	0.8	0.2	0.4	1.3
Europe[4]	2016	19.4	5.2	24.6	10.4	5.9	2	10.4
South Korea[5]	2013	10.8	3.1	13.9	-			10.9

In Australia, recycling rates were provided in 2002, with BFS accounting for about 83% (Granulated 100%, Air-cooled 71.4%), SS (BOF 63.8% and EAF 54.2%)[3]. In the U.S., about 150,000 tons of FS are expected to be produced by 2017[6]. In South Korea, the recycling target rate for BFS is set at 95% and the following recycling applications are proposed[7].

Table 2. Recycling applications of FS

No.	Applications	No.	Applications
1	Cement materials	9	Aggregates for roads and asphalt concrete
2	Concrete admixtures	10	Aggregates and materials for ceramics
3	Siliceous fertilizer raw materials	11	Drainage aggregate (BFS)
4	Brick, concrete aggregates	12	Anti-slip aggregate
5	Aggregates for embankment	13	Retaining wall and backfill material
6	Aggregates for restoration	14	Rubbles for the foundation
7	Aggregates for shore protection	15	Rock wool materials
8	Backfill materials for public water reclamation	16	Steel materials



Meanwhile, South Korea's FSproduction has increased by more than 3% every year since 2010, but the industry is faced with difficulties in acquiring land for aging, increased processing costs due to the absence of demand outside the existing recycling field[8]. BFS is used more than 75% for cement and concrete aggregate in Europe and South Korea, and about 16% is used for embankment only in South Korea. In Europe, about 21% is used for road construction, while in South Korea, about 5% is used[4]. In the case of SS, in South Korea, about 44% is used for embankment, 35% for road construction. About 46% of SS in Europe is used for road construction[5].

2.2 Coal Combustion By-products (CCBs)

The following Table 3. shows the amount of CCBs generated and recycled around the world in 2013[9].

Table 3. Annual Production and Recycling of CCBs (Coal Ash)

Countries	Production (Mt)	Recycling (Mt)	Recycling rate (%)
Australia	13.1	6	45.8
Canada	6.8	2.3	33.8
China[1)]	395	265	67.1
EU15	52.6	47.8	90.9
India	105	14.5	13.8
Japan	11.1	10.7	96.4
Middle East & Africa	32.2	3.4	10.6
United States	118	49.7	42.1
Asia (Other)[1)]	16.7	11.1	66.5
Russia	26.6	5	18.8
Total	777.1	415.5	53.5

1) Non-WWCCPN countries

Approximately 54% of the world-wide CCBs are being recycled. Japan and Europe have a high recycling rate of over 90%, while the Middle East and Africa, India and Russia have a low recycling rate of less than 20%. In South Korea, the recycling target rate of CCBs is set at 75%, Table 4 summarizes recycling applications of CCBs as recommended by the Korean Government [7].

Table 4. Recycling applications of CCBs

No.	Applications	No.	Applications
1	Concrete admixtures	9	Cement clinker raw material
2	Cement materials	10	Drainage aggregate (BA)
3	Lightweight aggregates	11	Ceramics materials
4	Secondary raw material for cement	12	Rubber, plastic filler
5	Aggregates for embankment	13	Abrasives, coating, thermal insulation materials
6	Aggregates for restoration	14	Steel materials
7	Aggregates for roads construction	15	Fertilizer raw materials
8	Wood adhesive raw material		

The current status of CCBs recycling in South Korea, U.K., U.S.and Australia is as follows: In South Korea, concrete and cement raw materials, and in the U.K., concrete and cement raw materials and lightweight fine aggregates were found to be highly utilized. This is attributable to the high recycling rate of Fly ash. This is considered to be due to the high recycling rate of the Fly ash. In the United States, about 25% was used to filling application, and in Australia, about 50% was used for mine reclamation and road construction[10].

3. Research and Development Status

In South Korea, it is allowed to use of BFS cement, fly ash cement (Class 1, 2) and blast furnace slag aggregate in interlocking blocks[11]. INTERPAVE, in the U.K., recommends that BFS be used as a coarse aggregate of base/subbase when paving concrete blocks. The following is a summary of representative studies using FSand CCBs as concrete block pavement and permeable concrete pavement materials[12].

Abdelbary, A. and Mohamed, A. R. (2016) investigated the strength, abrasion resistance, absorptivity and bulk density of concrete blocks usingEAF slag as a coarse aggregate. The results show that the strength, abrasion resistance superior than when Limestone aggregate was used. Although the surface texture become rougher and the splitting tensile strength was decreased, all of them were within the permissible range[1]. Choi, J.J. and Choi, D.S. (2007) concluded that BFS and SSaggregate can be used up to 50% for the replacement of crushed aggregate[13]. Uygunoglu, T. et al. (2012) analyzed the effect of FA content on PCIBs using FA. As a result, the compressive strength of the block decreased as the substitution rate increased, but FA increased the permeability, porosity and the resistance to Alkali - Silica Reaction (ASR)[14]. Park, J.B. (2008) confirmed the water-retantive performance of the block by using the bottom ash as aggregate, through the compressive strength, water absorption and water retention test[2].



There is also an example on which BFS and CCBs at the same time in a concrete block. Atici, U., & Ersoy, A. (2008) used Portland cement, FA, and BFS in the concrete interlocking paving block. Compressive strength, splitting tensile and flexural tensile strength, rebound hardness and abrasion resistance were measured. As a result, it was shown that FA, BFS can replace cement by 10-20%, 30-40%, respectively, based on weight replacement ratio[15].

4. Prospect of FS, CCBs in Concrete Block pavement field

Among FS, BFS is used as cement and concrete raw material, and SS is mostly recycled for embankment and road base/subbase aggregates. In order to achieve the target BFS recycling rate for each country, new recycling fields with high added value should be settled. As a result, basic researches on the recycling method of FS havebeen carried out in the field of concrete block pavement, and its utilization as block aggregate has been suggested. Particularly, when SS is used as coarse aggregate of concrete block, it is found to be advantageous in terms of strength and abrasion resistance. However, the BOF slag has various properties depending on raw materials, treatment process. Furthermore, because BOF slag contains CaO component, pretreatment process such as aging and sprinkling is necessary in order to use it. Thus, quality control should be strictly carried out according to the standards of the country concerned.

With regard to CCBs, it is most important to increase the recycling rate of BA, which is becoming increasingly important as an aggregate, drainage layer, road base/subbase aggregate. In the future, it is expected to increase the usability as coarse aggregates of blocks. On the other hand, FAhas a high recycling rate as concrete/cement admixture, but the annual amount of recycled material is not changed so much that new recycling methods are needed. In the field of concrete block pavement, it is expected to be able to generate synergy with the result of recent research on lightweight aggregate and permeable concrete using FA.

References

[1] Abdelbary, A.; Mohamed, A.R., The Impact of Incorporating Slag Aggregates on the Abrasion Behavior of Concrete Paver Blocks. Landsc. Archit. Reg. Plan, 2016, 11.

[2] Park, J.B., A Study of the Water-retentive Block using Bottom Ash. Proceedings of the Architectural. Institute of Korea, 2008 Volume 28(1), pp. 503506.

[3] Australiasin Slag Association, A Guide to the Use of Iron and Steel Slag in Roads. ISBN 0 2002, 9577051, 58.

[4] EUROSLAG, EUROSLAG Statistics 2016.

[5] Yoo, J.H., Recycling Plan for Promoting Waste Recycling Production, Recycling status and Prospect of Ferrous Slag. Proceedings of Korean Environmental Dredging Society, 2016, pp. 23-34

[6] Ober, J.A. Mineral Commodity Summaries 2018; US Geological Survey: 2018; p 86.

[7] Ministry of Environment, Recycling Guidelines for Ferrous Slag and Coal Ash Companies, 2016, South Korea

[8] Choi, J.S., The Status and Utilization Prospect of Steel Making Slag, Review of Architecture and Building Science, 2012 Volume 56(8), pp. 18-21.

[9] Heidrich, C.; Feuerborn, H.J.; Weir, A. In Coal combustion products: a global perspective, World of Coal Ash Conference, 2013 pp 22-25.

[10] Suh, D. H.; Maeng, J. H., A study on expanding the recycling of coal ash for minimizing

environmental impact imposed by the establishment of thermal power plant ash ponds. Journal of Environmental Impact Assessment, 2015, Volume 24(5),

[11] Korean Industrial Standards Committee, Concrete Interlocking Block for Side Walk and Road – KS F 4419, 2016, Korean Standards Association, Seoul, South Korea

[12] INTERPAVE, Permeable pavements: Guide to the design, construction and maintenance of concrete block permeable pavements. 6 ed.; INTERPAVE Leicester: 2010.

[13] Choi, J.J.; Choi, D.S., Influence of the Types and Grading of Aggregate on the Properties of Porous Concrete. JOURNAL OF THE KOREAN SOCIETY OF CIVIL ENGINEERS A, 2007, 27 (3A), 393-400.

[14] Uygunoglu, T.; Topcu, I. B.; Gencel, O.; Brostow, W., The effect of fly ash content and types of aggregates on the properties of pre-fabricated concrete interlocking blocks (PCIBs). Construction and Building Materials, 2012, 30, 180-187.

[15] Atici, U.; Ersoy, A., Evaluation of destruction specific energy of fly ash and slag admixed concrete interlocking paving blocks (CIPB). Construction and Building Materials, 2008, 22 (7), 1507-1514.