DEVELOPMENT OF PERMEABLE INTERLOCKING BLOCKS USING SEWAGE SLUDGE MOLTEN SLAG

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SUMMARY

The recent growth of Japanese cities means more roads paved with asphalt or concrete, which do not allow rain water to permeate the ground. This in turn causes various problems including flooding,limited plant growth and land subsidence. To solve these problems,intensive research has been directed to develop a porous asphalt or concrete road surface, which allows rain water to permeate the ground. The authors have developed water-permeable interlocking blocks mainly comprising molten slag obtained by melting industrial sewage sludge. These new blocks are presently in use at 15 locations (approximately 4,000m^2), including parking lots and sidewalks. As waste recycling becomes increasingly important, the new blocks are expected to be used more widely in the future.

This report describes the commercialization process, material properties, and serviceability of the new water-permeable interlocking blocks.

1. Introduction

As sewage systems have spread and sewage treatment techniques improved, the sludge discharged from sewage treatment plants has been steadily increasing, and its disposal is a grave social concern.

The landfill method has conventionally been used to dispose of sewage sludge. Recently, however, as it has become more and more difficult to find landfill sites,incineration has been used to reduce the volume of sewage sludge. However, problems remain with this method as well,such as flying ash,elution of heavy metals, and the continued need for landfill sites, calling for the development of a new treatment method to replace incineration.

Given this background,the authors commenced the development of a coke-bed furnace sewage sludge melting and recycling process, utilizing coke as an auxiliary fuel.

In this process, sewage sludge and a small quantity of coke are fed into a vertical shaft furnace, where the combustible matter in the sewage sludge is incinerated on an extremely high temperature coke-bed while the incombustible matter (ash) is eluted, yielding a slag which can be used as a road material and concrete aggregate.

The authors developed water-permeable interlocking blocks (hereinafter called water-permeable ILBs) as one instance of recycling sewage sludge-derived molten slag.

This report describes the commercialization process, material properties,and serviceability of the water permeable ILBs.

2. The Coke-bed Sewage Sludge Melting and Recycling Process

A flow diagram of the coke-bed sludge melting and recycling process[1] ' is shown in Fig. 1.

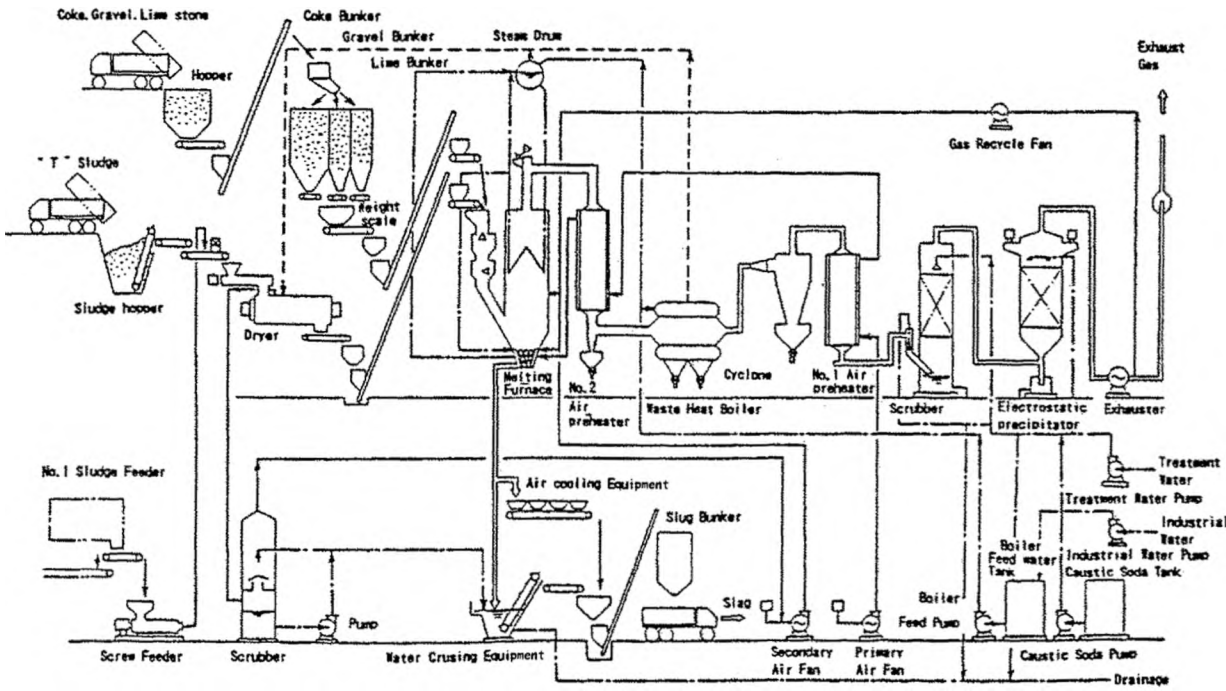


Fig. 1 Flow Diagram of the Coke-bed Sewage Sludge Melting and Recycling Process

Sewage sludge, supplied to the dryer by the quantity measuring feeder,is then heated indirectly by the steam from the exhaust gas boiler to dry it to approximately 40% moisture content; next it is sent to the furnace top together with an appropriate quantity of coke and a basicity adjustment agent; finally,it is fed into the melting furnace through the input hopper.

The furnace contains a coke-bed heated to over I, 500*C at its lower part. The sewage sludge is dried and heated by the high temperature exhaust gas from the coke-bed. The combustible matter is thus decomposed and incinerated, while the incombustible matter (ash) is melted on the coke-bed and turned into slag. The air to burn the coke and sewage sludge is input to the furnace through the blower.

Molten slag (1, 300”C to 1, 500"C) discharged from the melting furnace is crushed in water or quenched in air.

Sulfur in the sludge, partly fixed in the slag during the melting process,is mostly turned to SOx in the exhaust gas, which is removed in the process of flue gas desulfurization using magnesium hydroxide. The exhaust gas,treated by a wet electrostatic precipitator to remove dust and prevent white smoke emission,is then emitted from the stack into the atmosphere.

Heat is recovered to preheat the air for incineration and to serve as a heat source for the dryer. In the latter case, heat is recovered in the from steam by the boiler in the melting furnace or by the exhaust gas boiler in the exhaust gas treatment system.

Excessive steam is recovered as electricity from the turbine generator or used to power the turbine driver. Excessive steam is also used for air-conditioning and hot-water supply within the site.

3. Laboratory Experiments

3.1 The applicability of sewage sludge-derived molten slag as an aggregate of water-permeable ILBs

This is a study to determine the applicability of sewage sludge-derived molten slag to water-permeable ILBs.

1) Sewage sludge-derived molten slag

Sewage sludge-derived molten slag (hereinafter called slag) is a vitreous black substance. To obtain it, sewage sludge is heated to over 1, 400’C in a melting furnace; the inorganic matter thus melted is then quenched and coagulates.

The slag particle size differs according to quenching method; when water-crushed, it is like sand; when air-cooled, it is like gravel.

For water-permeable ILBs,air-cooled slag was used. The properties of the air-cooled slag are shown in Table 1. [2)]

Table 1 Properties of Air-cooled Slag Obtained from Sewage Sludge

Item	Treatment Plants	B Polymer	A $FeCla + Ca(OH)_2$	C $FeCl_3 + Ca(OH)_2$
Specific gravity	True	2. 97	2. 98	3. 10
	Bulk	1. 28	1. 23	1. 40
Ash content	FeO	2. 6	5. 4	7. 9
	CaO	29. 9	30. 9	32. 2
	P_2O_5	1. 4	1. 6	3. 4
	SiO_2	38. 6	36. 4	32. 4
	MnO_2	1. 1	1. 2	0. 6
	K_2O	1. 0	0. 5	0. 3
	Al_2O_3	15. 1	14. 2	12. 5
	MgO	3. 3	2. 9	3. 0
	TiO_2	0. 8	0. 8	0. 7
Ash Base(%)	Others	6. 2	6. 1	7. 0
Basicity	(CaO/SiO_2)	0. 77	0. 85	0. 99
Melting temp. (°C)	Softening point	920	920	1190
	Fusing point	1200	1200	1200
	Pouring point	1220	1230	1250

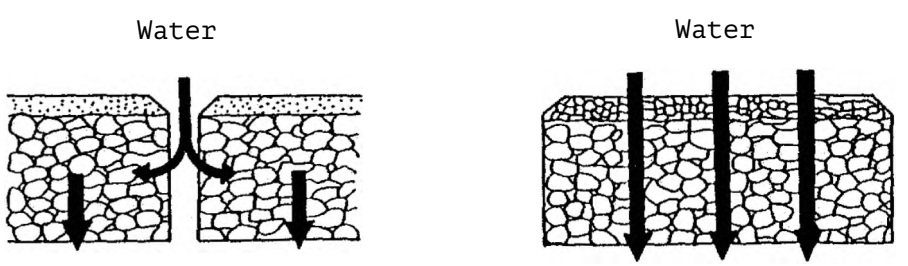
2) Specifications of water-permeable ILBs using slag

The specifications of slag-containing water-permeable ILBs to be used for concrete aggregate are shown in Table 2.

Table 2 Specifications of Water-permeable ILBs

Item	Standard value	Target value
Bending strength (MPa)	3. 43	3. 92
Porosity (%)	17	20
Permeablility coefficient(cm/sec)	1.0×10^{-2}	1.0×10^{-2}
Water permeance structure	A :Water-permeable joint type (Fig. 2- (1))	
	B1:Water-permeable surface type (Fig.2-(2))	

The water-permeable joint type (A) allows rain water to spread from the joints to the porous base and permeate into the ground from the bottom. The water-permeable surface type (B1) absorbs water through its porous surface. Water permeance structure is shown in Fig. 2.



(1) Water-permeable joint type (A)

(2) Water-permeable surface type (B1)

Fig. 2 Water-permeance Structure of Water-permeable ILBs

The process of developing water-permeable ILBs using slag as aggregate

The process of developing water-permeable ILBs using slag as aggregate is shown in Fig.3.

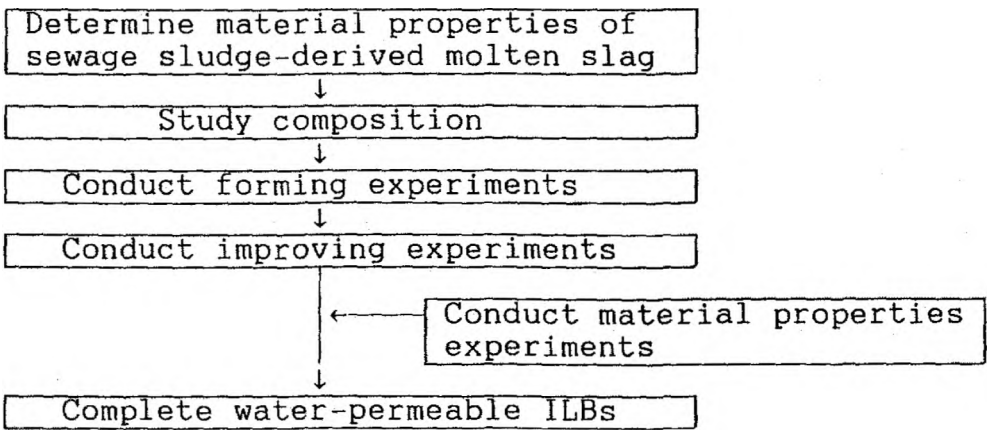


Fig. 3 Development Process of Water-permeable ILBs Containing Slag

3) Results of studying experimental blocks

(1) Materials

The materials and properties of aggregates are shown in Tables 3 and 4.

Table 3 Materials

Cement	Portland cement	Chichibu Cement Co. , Ltd.
Coarse aggregate	1) Crushed slag	
	2) No,6 Crushed stone	Ryogami Metal Co. , Ltd.
	3) No,7 Crushed stone	Ryogami Metal Co. , Ltd.
Additive	Mighty 150	Kao Corporation

Table 4 Results of Aggregate Material Tests

Type	Screen Passing Ratio (%) 15	10	5	2. 5	1. 2	0. 6	0. 3	0. 15	FM
Crushed slag	100	54	21	14	—	—	—	—	6. 11
No,6 Crushed stone	100	78	12	2	—	—	—	—	6. 08
No,7 Crushed stone	—	100	87	14	3	2	2	1	4. 91

Specific Gravity Surface-dry Condition	Specific Gravity Absolutely-dry Condition	Water Absorption (%)	Bulk Density (kg/m^3)	Solid Content (2)	Decantation (*)	Soundness (%)
2. 72	2. 71	0. 36	1720	63. 5	0. 34	1. 6
2. 68	2. 67	0. 54	1520	57. 0	1. 88	1. 1
2. 66	2. 63	1. 29	1450	55. 2	3. 20	0. 1

(2) Composition

Composition of concrete base is shown in Table 5.

Table 5 Composition of Concrete Base Using Water-permeable ILBs

No,	Unit Quantity (Kg/m^3) Cement	Water	Crushed Slag	No, 6 Crushed Stone	No, 7 Crushed Stone	Addi-tive	Combined FM
1.	400	92	2125	—	-	6	5. 34
2.	400	92	1594	-	520	6	5. 81
3.	400	92	1063	-	1039	6	5. 51
4.	400	92	531	398	1164	6	5. 44
5.	400	92	-	1047	1039	6	5. 49

(3) Test items and methods

Tests were conducted on (a) flexural strength (age: 7 and 28 days), (b)porosity,and (c)difference between mold and block (size measurements).

For each type of concrete block differing in composition as described in Table 5,six specimens were prepared using forming equipment, with a 2.0-second preliminary vibration and 6. 0-second main vibration.

Each specimen was measured for size and porosity and then left for standard curing until reaching the determined age. The span for flexural strength tests was set at 16 cm.

(4) Test results

(a) The relationship between the aggregate composition ratio and flexural strength.

The relationship between the aggregate composition ratio and flexural strength is shown in Fig. 4.

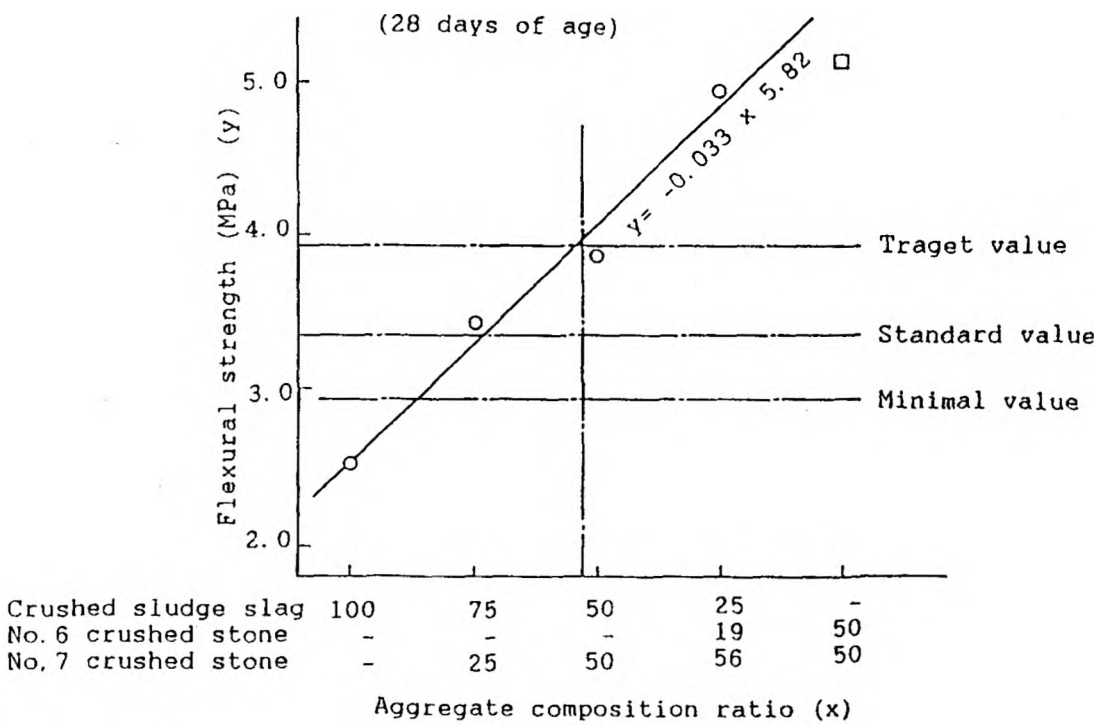


Fig. 4 The Relationship between the Aggregate Composition Ratio and Flexural Strength

The target proportional strength of water-permeable ILBs is set at 4. 17 MPa. From the relationship between the aggregate composition ratio and flexural strength, it was confirmed that up to approximately 50% slag can be included.

(b) The relationship between the aggregate composition ratio and porosity.

The relationship between the aggregate composition ratio and porosity is shown in Fig.5.

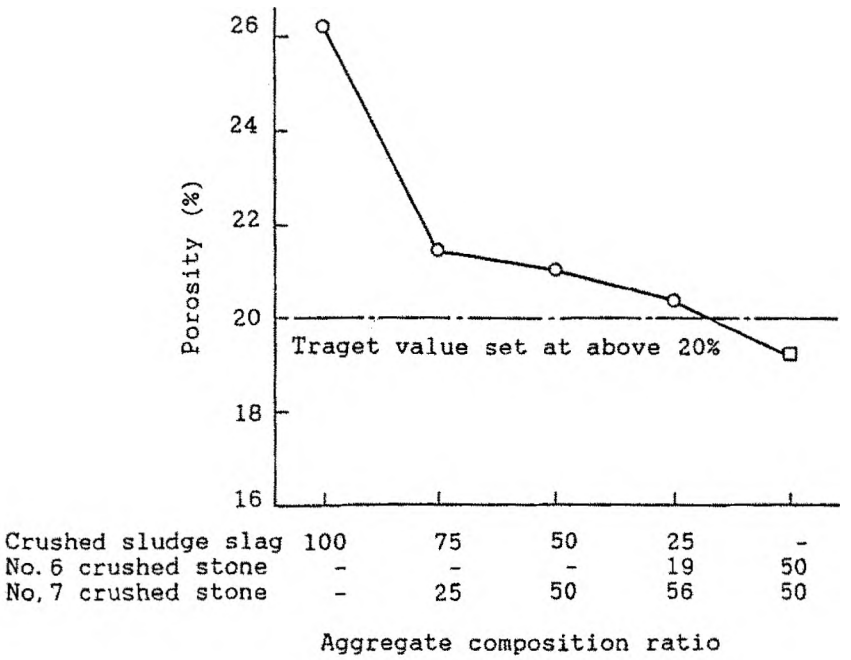


Fig. 5 The Relationship between the Aggregate Composition Ratio and Porosity

It was confirmed from Fig. 5 that,to obtain a target porosity of 20% under the conditions retaining the proportional strength of 4. 17 MPa, crushed slag can comprise up to 25% of the aggregate.

(c) The relationship between the aggregate composition ratio and the size difference between block and mold.

The relationship between the aggregate composition ratio and the size difference between block and mold is shown in Fig.6.

It was confirmed from Fig.6 that,when slag was included,the size difference between block and mold tends to be larger than when standard No. 6 and No. 7 crushed stone were used without slag. However, the discrepancy between the two is slight.

These results show that, when slag is included in the aggregate of water-permeable ILBs used as concrete base,slag can replace up to 50% of the crushed stone for both types A and Bl.

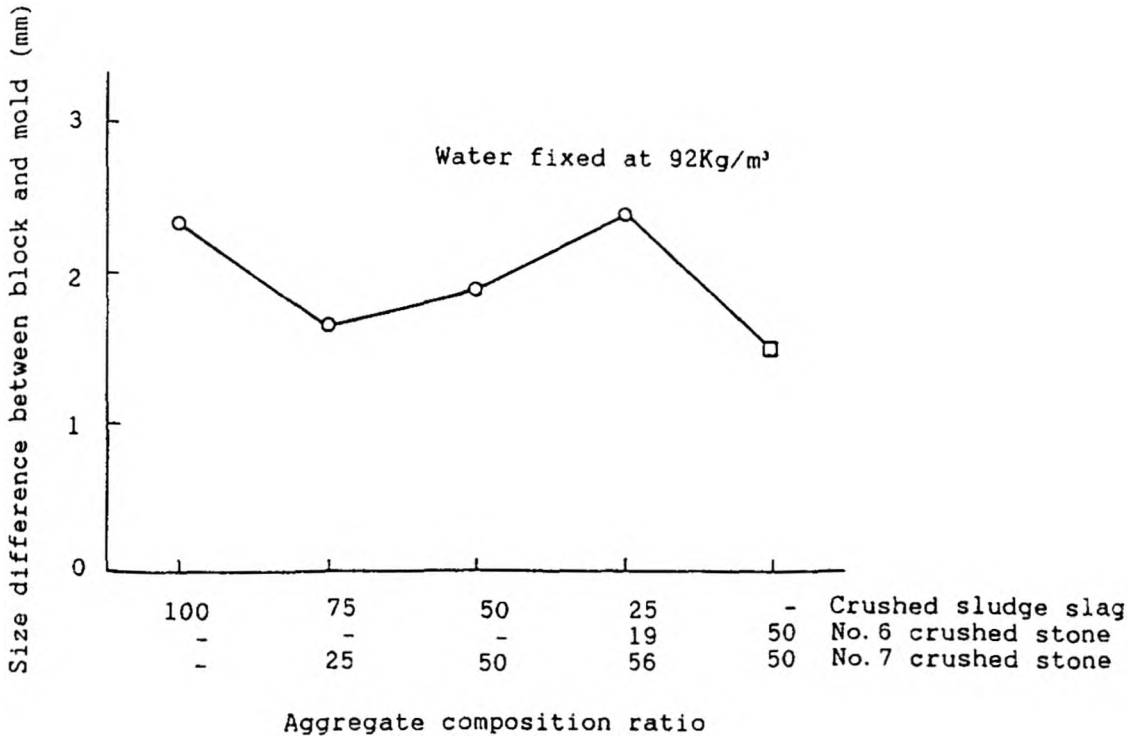


Fig. 6 Relationship between the Aggregate Composition ratio and the Size Difference between Block and Mold

3.2 Freezing and thawing tests.

The resistance to freezing and thawing of water-permeable ILBs containing slag as 50% of the aggregate of the base was studied. The method described in ASTM C 666, section of "Resistance of concrete to rapid freezing and thawing" was adopted for these tests.

The relative dynamic modulus of elasticity and mass reduction ratio at each cycle are shown in Table 6.

Table 6 Relative Dynamic Modulus of Elasticity and Mass Reduction Ratio at Each Cycle

Item	Type	Number of Cycles 0	30	60	90	120	150
Relative dynamic modulus of elasticity (%)	A	100	84.4	73.0	44.4	—	—
	B1	100	84.0	66.9	32.7	—	-
	B1*	100	91.9	87.5	74.7	65.2	40.0
Mass reduction (%)	A	0	1.4	2.4	11.3	-	-
	B1	0	1.6	2.8	23.6	-	-
	B1*	0	0.3	0.5	0.6	1.8	3.7

* Natural aggregate 100%

Table 6 shows that mass reduction became noticeable as soon as the number of cycles exceeded 60. The number of cycles and durability indexes when the relative dynamic modulus of elasticity marked 60% are shown in Table 7.

Table 7 Number of Cycles and Durability Indexes

Slag	Type	Number of Cycles at 60% Relative Dynamic Modulus of Elasticity	Durability Indexes w
Contained	A	73	15
	Bl	65	13
Not contained	Bl	125	25

The durability indexes of water-permeable ILBs containing slag ranged from 13% to 15%, slightly lower than when no slag was used.

This means that, when slag was present in water-permeable ILBs, the resistance was slightly lower than when it was not used.

Possible reasons: (I) Slag is not as strong as crushed stone sold on the market, and
(II) Being vitreous, slag is not suited to concrete.

Therefore, at cold temperatures, the use of slag is restricted. It is necessary to improve slag strength to solve the above problems. One means of greatly improving slag strength may be to crystallize it. For this purpose, the authors are trying to find suitable means of cooling during slag production.

4. Water-permeable ILBs Permeability Coefficient Tracking Study

Field tests were conducted to determine the permeability of water-permeable ILBs immediately after construction,as well as to track changes in it over two years.

These tests were conducted on 460m^2 of mass-produced water-permeable ILBs, containing 30% slag,laid at Settu pumping station in Osaka Prefecture. The falling head method, in which the time required for the predetermined quantity of water to permeate was measured in seconds,was used for measuring.

Measurements were conducted 3 or 4 times at each measuring spot, with the average taken as the permeability coefficient. The results of the measurements are shown in Table 8.

Table 8 Results of Permeability Tests (Type A)

Unit Ki_5 (cm/sec)

Measuring Sport No,	Fist Time Apr. 14, 1988	Second Time July 20, 1988	Third Time Oct. 20, 1988	Fourth Time Apr. 26, 1989	Fifth Time Apr. 25, 1990
1.	5.30×10^{-2}	3.54×10^{-3}	4.67×10^{-4}	3.57×10^{-4}	1.01×10^{-3}
2.	9.08×10^{-2}	1.39×10^{-2}	8.03×10^{-3}	1.12×10^{-3}	9.01×10^{-3}
3.	4.24×10^{-2}	1.53×10^{-2}	2.26×10^{-3}	6.65×10^{-4}	1.97×10^{-3}
4.	2.45×10^{-2}	9.15×10^{-3}	1.08×10^{-3}	3.26×10^{-4}	2.11×10^{-3}

The permeability coefficient of materials used for water-permeable pavement in Japan is generally 1. 0×10^{-2} cm/sec. As a result of the two-year tracking study, it became clear that the permeability coefficients met the standard of 1.0×10^{2} cm/sec immediately after construction, then showed a tendency to decline after three and six months, finally stabilizing after a year. These coefficients were almost the same as those of sand, which indicates that the water-permeable ILBs can be put to practical use.

5. Conclusion

This report describes the development of water-permeable ILBs using slag as concrete aggregate, presenting one instance of effectively recycling and utilizing molten slag obtained from sewage sludge.

Water-permeable ILBs have been put to practical use at 15 sites, including parking lots and sidewalks, with an area totaling 4, $000 m^2$; demand is expected to increase.
However,partly because the water-permeable ILBs are produced upon receipt of order,and partly because it is still costly to adjust slag particle size, the proportion of slag used is presently limited to below 30%, much lower than the technically possible ratio of 50%.

In the future,as the number of melting facilities and the generation of slag increase, bulk orders will also increase,thereby reducing the cost of adjusting particle size, and thus,maximizing the permissible proportion of slag. At the same time, by employing an ordinary production line,costs will be reduced, and competitiveness with conventional products already on the market will increase in terms of both cost and capacity, which will promote waste recycling.

Waste recycling and global-scale environmental preservation have recently become the focus of much attention. The authors will continue research and development efforts which will contribute to effective waste recycling.

Reference

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