UTILIZATION OF GLASS CULLET FOR SAND-CUSHION LAYER OF ILB PAVEMENT

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ABSTRACT

Turning industrial by-products into a reusable resource has a recognized effect in holding down the extraction of natural resources and extending the life of waste disposal sites. A problem faced by the construction industry is the likely drying up of supplies of aggregate, and considerable interest has been shown in the use of an industrial by-product as a substitute material. Interlocking block (ILB) paving has so far been used mainly as a decorative paving material for sidewalks and paths in parks, but as it is resistant to rutting, it is now being increasingly used as a surfacing material for roads. New uses have been developed for waste glass, and this research examines the suitability of glass cullet, or crushed waste glass, as cushioning sand for ILB paving, a product whose commercial use is spreading. Glass cullet is made from crushing glass containers to the consistency of sand. Although its crystal structure is different from natural aggregate, there is no great difference in its composition, and with no harmful components it is perfectly safe. Glass cullet has angular-shaped grains that are highly deformation-resistant and not prone to fragmentation. From these properties it was judged to be suited for use as cushioning sand under ILB paving.

1.INTRODUCTION

Turning industrial by-products into reusable resources is currently generating considerable interest throughout society from the viewpoint of holding down extraction of natural resources, and lengthening the life span of waste disposal sites. In April 1997, "The Row for promotion sorted connection and recycles of containers and packaging" came into effect, and allocation of responsibility with regard to waste disposal among consumers, enterprises and local government was clarified. Local government initiated the efficient collection and reprocessing into usable resources of materials that had previously been disposed of as waste, and by such means systems were established to bring industrial by-products back to the market place as resources. At the same time, supplies of aggregate, an important construction material, are drying up and extraction of high quality natural resources is being restricted, so industrial by-products of equivalent quality are increasingly likely to be used as construction materials.

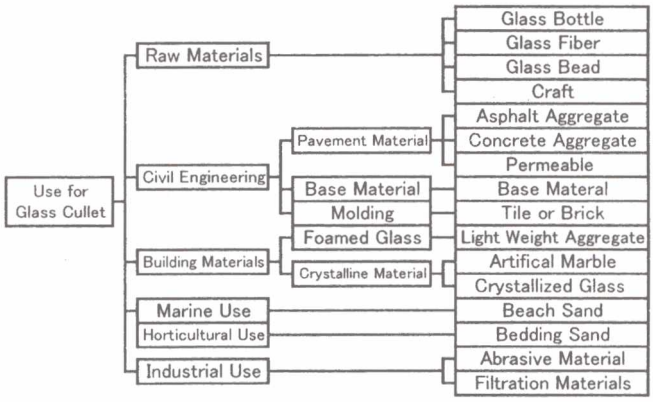

Figure 1 Glass Cullet Applications

The object of this study is glass cullet, a material made from glass bottle waste. In 1995, 1.37 million tons, or about 60% of the domestic production of 2.23 million tons of glass bottles, was recycled. But the remaining 860,000 tons, as well as imported glass containers, were disposed of

as waste. For recycling, glass bottles collected from households and commercial premises are crushed, graded, and washed to be turned into raw material used for the production of new glass bottles, or for other uses. The crushing, grading, and washing processes depend on how the material is to be used, and it is processed into many different forms, in consistency ranging from sand to powder. As glass cullet is angular-shaped in its crushed state, and does not easily fragment, one possible use is as cushioning sand under interlocking block (ILB) paving. For this study, its suitability for this purpose was evaluated through laboratory tests and a test paving project. The tests confirmed that glass cullet as cushioning sand under ILB paving performs at least as well as either the crushed sand or river sand currently used for the purpose.

2.PERFORMANCE REQUIRED FROM CUSHIONING SAND FOR ILB PAVING

2.1 Functions of Cushioning Sand

The functions of cushioning sand for ILB paving are set out in Design and construction of Interlocking concrete block pavement [1] are summarized as follows:

(1) A separating layer that prevents cracks in the subgrade from reaching the paved surface.
(2) A supporting layer allowing the ILB paving to be laid evenly.
(3) A supply of sand to fill under the joints.

2.2 Quality Characteristics of Cushioning Sand

The quality characteristics required to fulfill the functions of cushioning sand are as follows:

(1) High shear resistance angle
(2) Grain strength high enough to resist crushing by the weight of vehicular traffic
(3) Angular grain shape

On quality of the sand material (cushioning sand; sand for joints) to be used with ILB paving, Interlocking block pavement design and construction guidelines [2] are shown in Table 1.

Table 1 Quality Characteristics of Joint Sealingand Cushioning Sands

	Grain Max (mm)	Passing 75 μm (%)	Remarks
Joint Sealing Sand	2.36	<10	Good Quality
Chushioning Sand	4.75	<5	Coase Sand

3.LABORATORY TESTS ON CUSHIONING SAND:

Glass cullet is an industrial by-product made by crushing and grading glass bottles, and it differs in terms of its structure and properties from the naturally-occurring crushed sand and river sand that

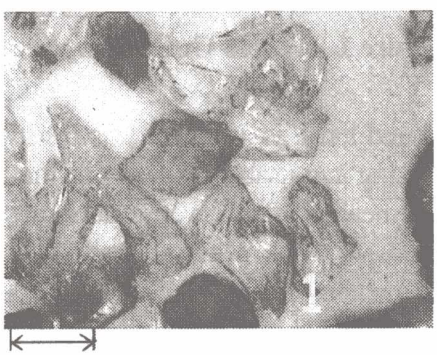

Photo 1 Glass Cullet

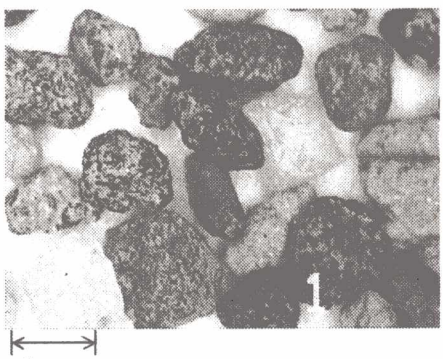

Photo 2 River Sand

are conventionally used with ILB paving. Therefore, the physical and dynamic properties of glass cullet were determined from a series of tests, and its suitability as cushioning sand was studied through a comparative evaluation with natural sands.

3.1 Physical Properties

The results of the physical properties are shown in Table 2. Grain size distribution for the test sands (crushed sand, river sand, and glass cullet) are shown in Figure 2.

Table 2 Results of Physical Properties

Item		Cipher(Unit)		Crush Sand	River Sand	Glass Cullet	Remarks
Density Test	Soil Particle Density	ρ s	(g/cm3)	2.708	2.775	2.509	JGS T111-1990
	Max.Density of Sand	ρ dmax	(g/cm3)	1.799	1.600	1.675	JGS T161-1990
	Min.Density of Sand	ρ dmin	(g/cm3)	1.398	1.317	1.301	
	Relative Density	Dr	(%)	96.0	91.0	103.0	
Grain Size Test	Uniformility Coefficien	Uc		8.2	4.1	6.4	JGS T131-1990
	Coefficient Curvature	Uc′		1.5	1.0	2.0	

Uc>10 : Good Grain Size Uc=4-5: Poor Grain Size

Uc'=1-3 : Good Rain Size

The quality characteristics of the test sands determined from the physical properties can be summarized as follows:

(1) Measurements showed that the glass cullet was slightly lower in density and lighter than the two natural sands. The specific gravity of the glass was around 2.50 - 2.60, which was an appropriate value.

(2) Relative density is an index that shows the compaction characteristics of materials of different shapes and grain size distribution. Glass cullet showed the highest relative density and is thus most easily compatible.

(3) In terms of uniformity coefficient, that indicates the range of the grain size distribution, and coefficient of curvature, that indicates the nature of the curvature, the test results differed slightly for each of the test sands. The values were lower for the river sand due to its single grain size.

(4) Measured against an index intended for purposes where compaction is used to produce high density, some test sands come in the 'poor grain size' category, but the test sands all came within the recommended range of grain size published in 'Design and Construction of Interlocking Concrete Block Pavement'.

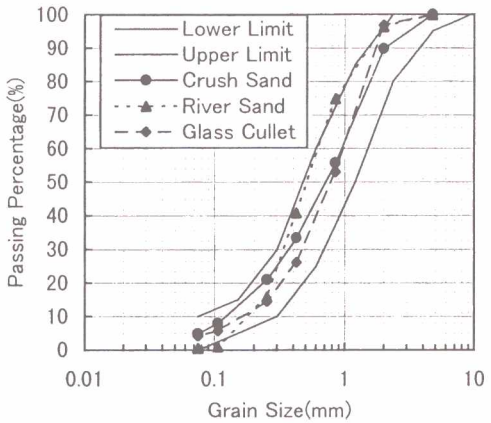

Figure 2 Grain Size Distribution

3.2 Relationship Between Density and Permeability

The results of the density and permeability tests are shown in Table 3.

Table 3 Results of Density and Permeability Tests

Item		Cipher(Unit)		Crush Sand	River Sand	Glass Cullet	Remarks
Density Test	Maximum Dry Density	ρ ds max	(g/cm3)	1.778	1.75	1.69	JGS T711-1990
	Soil Particle Density	ρ s	(g/cm3)	2.708	2.775	2.509	—
	ρ ds / ρ s		(%)	65.7	56.6	67.4	
Permeability	Cofficient of Permeability	K15	(k15cm/s)	0.023	0.016	6.18E-03	JGS T311-1990

Through these tests the compaction properties of the test sands were compared and evaluated.

(1) An evaluation of dry density against soil particle density showed the glass cullet to be the most easily compatible, as was also shows n by the relative density.

(2) The coefficient of permeability was lowest in the glass cullet, which was attributed to reduce spacing through compaction.

3.3 Triaxial Compression Test

The results of the triaxial compression tests are shown in Table 4 and Figures 3, 4 and 5.

Table 4 Cohesion and Angle of Internal Friction

Item		Cipher(Unit)		Crush Sand	River Sand	Glass Cullet	Remarks
Triaxial Compression Test	Coefficient	Cd	(kN/m2)	8.2	15.5	9.9	JGS T520,524-1990
	Soil Particle Density	φ d	(degree)	44.4	40.5	37.6	

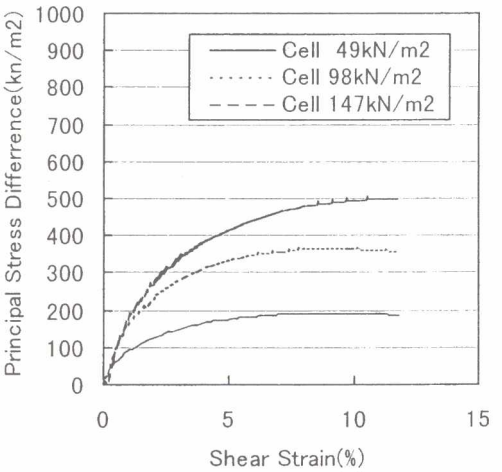

Figure 3 Result of Triaxial Compression Test for Glass Cullet

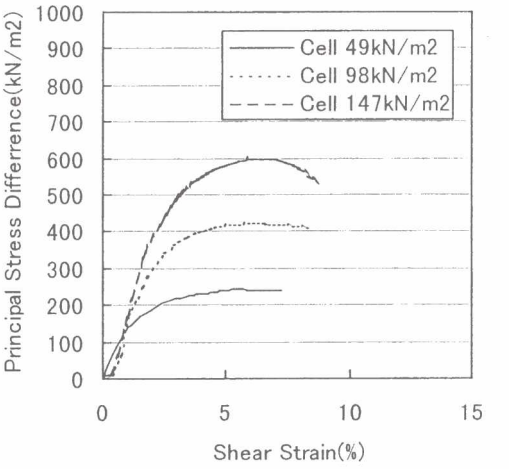

Figure 4 Result of Triaxial Compression Test for River Sand

The triaxial compression tests made a comparative evaluation of the shear characteristics of the three test sands: crushed sand, river sand and glass cullet.

(1) Principal stress differences with a cell pressure of 49kN/m^2 and axial strain of 5.0%, were 245kN/m^2 for the crushed sand, 240kN/m^2 for the river sand, and 180kN/m^2 for the glass cullet, indicating some

variation in deformation characteristics among the test sands.

(2) With regard to shear strength, the crushed sand and river sand showed a peak after which the stress rapidly decreased, however the glass cullet maintained the same value, indicating a difference in shear deformation characteristics with the crushed sand and river sand.

(3) As the stress increased, the sands exhibited elastic deformation, followed by crumbly grains and grain angle crushing. As the crushing proceeded there were loosening between the grains, followed by continuous slipping, rotation and deformation between grains.

With the shear stress maintained, deformation continued and reached shear failure. The stress-strain relation of glass cullet resembles the shear characteristics of loosely packed sand, and with no lowering of the compaction density, it can be expected to show the same tendency as that of crushed sand and river sand. Glass cullet contains grains of a slightly different shape from those of crushed sand and river sand, it has lower surface roughness than natural sands and slips easily, and there is little crushing of grain angle. As a factor accounting for the test results, it was thought that these material properties have the effect of softening externally imposed stress, and there was thus no rapid decline in stress.

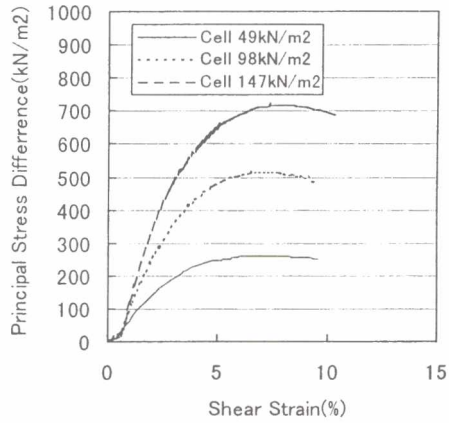

Figure 5 Result of Triaxial Compression Test for Crushed sand

3.4 Compaction Tests

The results of the compaction tests are shown in Figures 6 and 7.

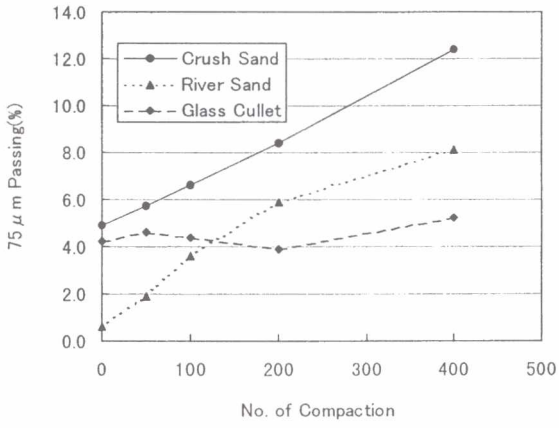

Figure 6 Crushing-Permeability Test

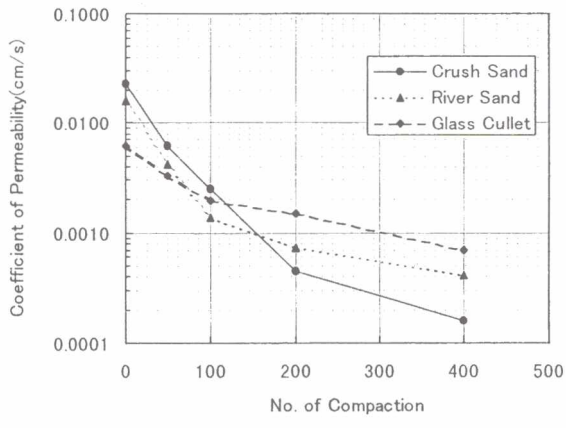

Figure 7 Crushing-Grain Size Test

It was conjectured from the stress-strain relation in tri-axial compression tests that there would be differences among the test sands in the grain angle crushing occurring with increased stress, and so crushing-permeability and crushing-grain size tests were conducted to evaluate grain strength.

(1) As the number of compactions increased, the permeability performance of the crushed sand and river sand tended to decline rapidly. The glass cullet showed a smaller rate of decline than

the natural sands.

(2) An increase in powder due to compaction was much more pronounced in the crushed sand and river sand, and was thought to be the factor causing the drop in permeability performance.

(3) There was relatively less reduction to powder in the glass cullet when external force was applied,compared to the natural sands, and differences among the test sands in grain angle strength, predicted from the results of the tri-axial compression tests, were confirmed, the glass cullet having the greatest strength of the three.

3.5 Summary of Laboratory Tests

The industrial by-product glass cullet is molten silica that is rapidly cooled and solidified. It differs from natural sands in that it is not crystalline in structure, whereas natural sands are formed from combinations of several different minerals and are crystalline. This is thought to account for the differences in the test results. These particular laboratory tests were selected to evaluate the performance required of cushioning sand for ILB paving, and from the test results glass cullet was judged to have a performance that equals or exceeds that of natural sands (crushed sand and river sand).

4. TEST PAVING PROJECT

The suitability of glass cullet for use as cushioning sand for ILB paving was evaluated from the results of a test paving project carried out in Shirakomachi, Chosei-gun, Chiba prefecture.

4.1 Project Outline

The outline of the test paving project is in follows:

(1) Dates: 20 September to 21 October 1998

(2)Location: Route number 202, Shirakomachi, Choseigun, Chiba prefecture

(3)Traffic classification: A

(4) Subgrade bearing capacity: CBR = 3%

(5) Cushioning sand:Glass cullet, River sand

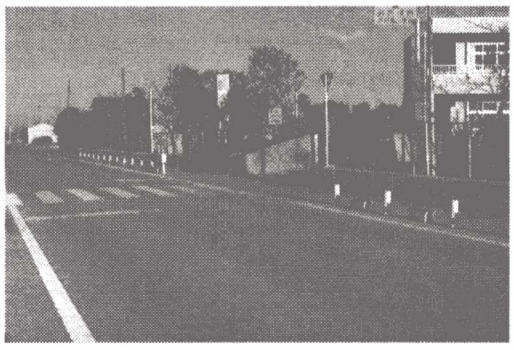

Photo 3 Test Paving

4.2 Evaluation Method

In follow-up surveys, various experimental tests were carried out on structural aspects of the test ILB paving. The results of those tests relating to the performance of the cushioning sand were used to make a comparative study of the suitability of glass cullet and river sand.

4.2.1 Degree of Deflection Due to FWD

Time elapsed indicates the loading history of the weight of the traffic. The degree of deflection showed the same declining trend for both river sand and glass cullet. This is thought to be due to the locking effect brought about by aggregate with a grain size distribution close to single grain size. Immediately after the installation work, the degree of deflection of the glass cullet was lower than that of the river sand, suggesting that in grain size distribution, grain strength and shape, its resistance to deformation is slightly superior.

4.2.2 State of Test Paving

In ILB paving, the individual blocks are linked along their points of contact, so the quality of the joint sealing sand supporting the side surfaces of the blocks also has a significant effect. Regarding the state of contact of the blocks, a change in the joint sealing sand due to the effect of the weight of the traffic causes some irregularity where the blocks are linked, and this may lead to damage of the blocks. As a result of the test paving project, it was found that when glass cullet was used as the joint sealing sand there was less change to the thickness of the joints, and a lower rate of damage to the blocks.

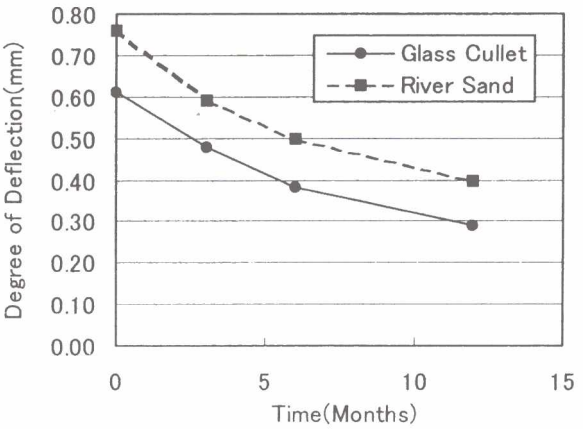

Figure 8 Hange in Degree of Deflection

4.2.3 Fragmentation of Cushioning Sand

In order for the load on the blocks caused by traffic to be conveyed evenly to the lower layer, one necessary characteristic of the cushioning sand is that the load will not crush it. Measurements of the fragmentation of the cushioning sand taken at points on the test paving selected by sampling, showed differing tendencies depending on the material. The results indicated that glass cullet is more resistant to fragmentation than river sand. This conforms to the results of the laboratory tests.

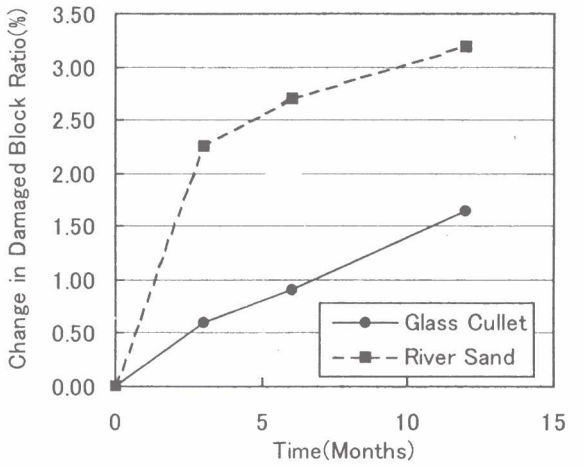

Figure 9 Change in Damaged Block Ratio

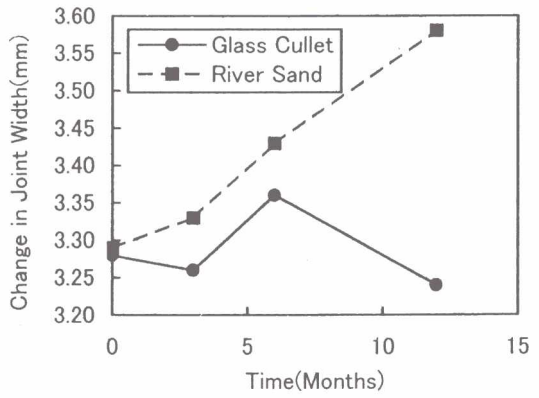

Figure 10 Joint Spacing

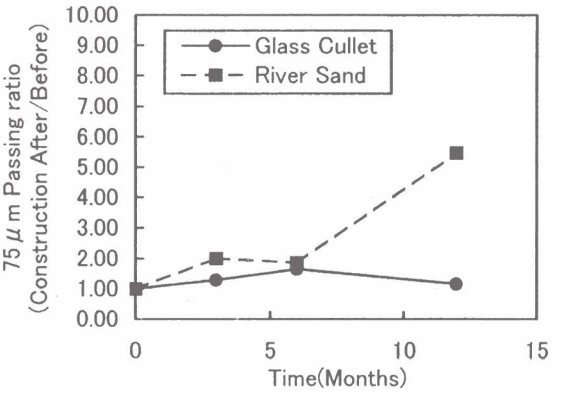

Figure 11 Fragmentation of Cushioning

4.3 Summary of Test Paving Project

An evaluation of its performance by means of a test paving project con firmed glass cullet's suitability as cushioning and joint sealing sand, as it performed at least as well as river sand. The material proper ties of glass cullet determined in the laboratory tests were confirmed through the test paving project. Glass cullet's distinctive characteristics: its angular grain shape and grain strength that resists fragmentation, work favorably to resist deformation in the cushioning layer, and enhance the stability of the blocks. It was therefore concluded that glass cullet is a suitable material to be used as cushioning sand for ILB paving.

5.CONCLUSION

A study was undertaken to evaluate the suitability of glass cullet as cushioning sand for ILB paving, by means of laboratory tests of its material properties, and a test paving project. Although some slight differences were observed in the material properties of the glass cullet , compared to the crushed sand and river sand conventionally used, in terms of the performance required as cushioning sand, it was evaluatedas being equal or superior to the natural sands. The substantial reasons for the superiority of glass cullet over natural sands can be uncovered through more detailed material engineering studies, and this will be the next issue for research.It is significant that high quality natural sands were selected for use in the comparative tests, and they provided favorable results.

Selecting cushioning sand from sources locally available may result in variations in quality, depending on the location of the source. In some regions it is difficult to obtain the sort of high quality sand used for these tests. The quality of glass bottles manufactured in Japan, however, is fairly uniform, and thus the quality of glass cullet, too, can be considered uniform across the country. Cushioning sand of consistent quality is regarded as leading to ILB paving of consistent quality. Reflecting the fact that industrial by-products are regularly being redistributed as usable resources, the reasonable price of recycled materials is also of significance, but more important is the fact that sup plies of a consistent quality can be obtained without any regional variation, and the opportunities for using them are growing.
By providing a recycling focus to encourage local governments to collect used glass containers, and through the promotion its use in public works projects, glass cullet is an industrial by-product that can increasingly be used in the area where it's generated. For these reasons the use of glass cullet as cushioning sand can be regarded as a highly realistic proposal.

The authors would like to express their particular thanks to the Environmental Bureau of Koshigaya City, Saitama Prefecture, for supplying t he glass cullet used in this research, and to Professors Yuji Miura and Yukio Todoroki, of the Development of Transportation Engineering College of Science and Technology Nihon University, for their guidance in the planning of the laboratory tests and test paving project and the formulation of the results. The assistance of all those involved is greatly appreciated.

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2. Inter locking block engineering association (1994) Interlocking Block Pavement Design and Construction Guidelines, pp.47.