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Applicability of sewage sludge ash (SSA) for paving materials: A study on using SSA as filler for asphalt mixture and base course material

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ABSTRACT

This study aimed at investigating two ways in which Sewage Sludge Ash (SSA) can be utilized. Namely, the study involves consideration of using SSA for a filler in asphalt mixture and secondly, involves the combination of SSA with fresh concrete, and then crushes the solidified mixture for use as a base course material. Following promising results, the study indicates that by using these two measures, 1,126,000 tons of SSA can be utilized annually compared to the 221,000 tons of SSA produced in Japan. On top of this, the study revealed that, if SSA is pulverized, the amount that is useable for pavement materials can be increased by more than two times.

Keywords. Sewage sludge ash, Recycling, Pulverization, Asphalt mixture, Base course material

INTRODUCTION

For municipalities that produce a large amount of sewerage sludge, the disposal of this sludge is problematic. In Japan, to reduce waste, 70% of sewerage sludge is incinerated. This results in a large amount of Sewage Sludge Ash (SSA). In 2011, 221,000 tons of SSA were produced in Japan. Of this amount, a very large amount is disposed of via landfill or used as raw materials for cement. In order to create a sustainable method of dealing with SSA an economic method to dispose of large amounts of SSA is necessary. Thus far, studies have largely confined themselves to applicability (example: fine aggregate (JI.Bhatty and KJ.Reid, 1989), admixture (J.Monzó et al., 1996), and asphalt filler (Al Sayed et al., 1995) etc.). This study was undertaken with the intent of investigating not only the applicability of SSA, but also the measures that are able to utilize large amounts of SSA.

In this study, the authors chose to focus on two measures of utilizing SSA. The first measure concerns the utilization of SSA as a filler for asphalt mixture and the second involves the combination of SSA with fresh concrete, and then the crushing of the solidified mixture for use as a base course material. In 2011, the amount of asphalt mixture and base course material produced in Japan, that did not contain SSA was 45,700,000 tons and 38,770,000 tons respectively. With this large and steady demand for construction materials, it is apparent that the measures of utilizing SSA outlined in this study are beneficial. There are, however, other reasons for utilizing these measures. One such reason is that SSA is easily dispersed into the environment. In addition to this, the leaching of toxic substances from SSA is also a problem that requires an alternative way of dealing with SSA waste. This study was conducted under the hypothesis that with the methods discussed, as the SSA is mixed with asphalt or cement, it is physically and chemically contained, making it possible to avoid the problems associated with scattering of SSA waste and the leaching of chemicals.

CHARACTERIZATION OF SSA USED

In this study, SSA taken from a Iwate Prefectural sewage treatment plant was used. The SSA used was fly ash obtained from a cyclone classifier after mechanically dewatered sludge was incinerated in a fluidized combustion bed. The characteristics of this SSA are shown in Table 1. The SSA was coarser than the limestone usually used as a filler for asphalt mixture and also had a larger BET surface area. The SSA also contained quite large amounts of phosphorus. The Leaching concentrations of used SSA are shown in Table 2. As the SSA was leaching arsenic and selenium, it was not able to be used as is.

Table 1. Characteristic properties of SSA used

		Unit	(Control) Limestone	Types of SSA used Original	Pulverized*	Testing method
Phosphorus (P) content		wt %	<0.1	12.6		Molybdenum blue method
Particle size	D90	μm	77	265	66	Laser diffraction
	D50		26	104	9.6	
	D10		3.6	19	0.48	
Flow property		%	32	120	65	Taken from "Hosou tyousa shikenhou binran : 2006"
Density		g/cm^3	2.730	2.715	2.727	JIS A 1202 (2009)
Tap density		g/cm^3	1.6	0.66	0.99	Used cylinder : JIS Z2504 : 2008 Tap speed : 100 taps / min Duration : 3 min Stroke: 10 mm
BET surface area		m^2/g	0.4	5.5	6.8	Nitrogen adsorption

*Pulverized : SSA pulverized using planet mill.

Table 2. Leaching concentrations of SSA used

Element	Leaching concentrations (mg/L) Types of SSA used: Original	Pulverized	JLT46 Standard limits*
Cd	0.003	0.002	<0.01
Pb	<0.002	<0.002	<0.01
Hg	<0.0002	<0.0002	<0.0005
Cr(VI)	<0.02	<0.02	<0.05
As	0.47	0.38	<0.01
Se	0.048	0.039	<0.01
F	<0.20	<0.20	<0.8
B	0.72	0.80	<1.0

*According to the test method and the standard limits in Japanese Environmental Agency Notification No.46.

The SSA had a notably different shape to limestone as shown in the cross section of the SSA in Figure 1. The clearest difference between SSA and limestone was the level of porousness. The possibility that this porousness can cause problems when it is used in cement mixture or asphalt mixture is high. With this in mind, the study used pulverized SSA in order to decrease the porousness of the SSA. The pulverized SSA was obtained using planet ball mill (Retsch : PM400) through placing 150 grams of SSA and twenty five 20φ alumina balls in a 500ml capacity alumina pot, which was then pulverized at an orbital speed of 300 rpm for 5 minutes.

The combined data from the pulverized SSA is included in Table 1, Table 2 and Figure 1. After being pulverized, the mean particle diameter of the SSA was only about 1/10 of the levels of the unprocessed SSA. In addition to this, the Tap density increased and the Flow property decreased (Table 1) From this it can be seen that by pulverizing the SSA, the porousness of the particles can be reduced. Furthermore, as shown in Table 2 the leaching concentration of Arsenic and Selenium did not increase.

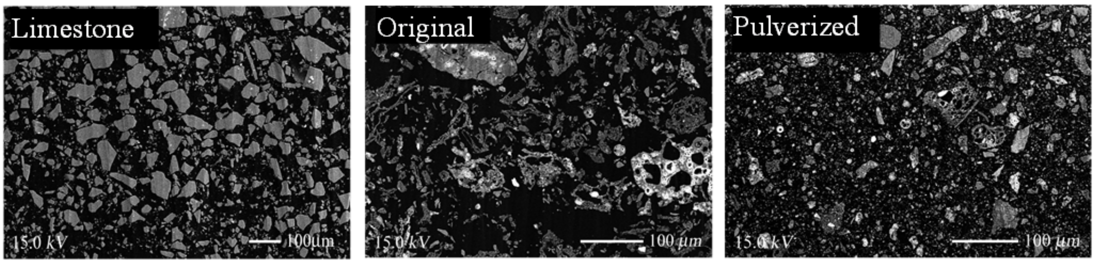


Figure 1. Cross sections of SSA

UTILIZATION AS FILLER FOR ASPHALT MIXTURE

Method. In the first test, the SSA was used as filler for asphalt mixture as an alternative to powdered limestone. The asphalt mixture type chosen for the study is the dense-graded asphalt concrete (20F) often used in the road surfaces in Iwate Prefecture. The binder used was straight-asphalt (80-100). In two separate mixtures, original SSA and pulverized SSA were used in place of limestone. The ratios were 15wt%, 30wt%, 45wt% and 100wt%. However when the original SSA was used at a ratio of 100wt%, the mixing process took a long amount of time and required large amounts of asphalt in pre-experiments. As a result, tests using this ratio of original SSA were abandoned. The levels of Optimum asphalt content (OAC) required for each replacement ratio were decided by using a Marshall stability test. From there, the retained stability, dynamic stability and splitting strength of each mixture was measured and the applicability of SSA as a replacement for limestone was judged.

Results and discussion. According to the results, SSA can be used as a filler for asphalt mixture but the quality of the asphalt mixture decreases. By referring to Fig.2 for OAC and Marshall stability, it can be seen that when original SSA is used, the required amount of asphalt increases. As asphalt is expensive, this result is undesirable. Also, the more original SSA that is used, the lower the Marshall stability level. In parallel with this finding, the dynamic stability and splitting strength of the mixture followed the same pattern. However as the degradation of results shown when using original SSA is within the Japanese standard (Japan Road Association, 2006) it is still possible to use a mixture at a replacement ratio of 45wt%. With a 45wt%, 22.5 kg of original SSA can be used per 1 ton of asphalt mixture. It was calculated that if this ratio was applied to the total amount of asphalt mixture produced each year in Japan, about 1,030,000 tons* of original SSA could be used as a filler. (*When filler makes up a ratio of 5wt% of the complete asphalt mixture.)

The problems that arose from using original SSA can be overcome through the use of pulverized SSA. In some cases, when using pulverized SSA the level of OAC required can be less than proportion required when using only limestone (Figure 2a). By using pulverized SSA, voids in mineral aggregate can be filled and the required effective asphalt content as well as the SSA's asphalt absorption levels can be decreased. The Marshall stability also showed a marked improvement (Figure 2b). This suggests that the Marshall stability decrease of the asphalt mixture is caused by the porousness of SSA. Furthermore the dynamic stability and splitting strength of the mixture showed great improvements. However, as shown in Fig.3 when using pulverized SSA, the residual stability of the mixture decreases. At a replacement ratio of 100wt% the residual stability falls below Japanese standards. The exact cause for the decrease in residual stability is still being investigated, but it has been found that the problem can be solved with the addition of a generic anti-stripping agent such as $Ca(OH)_2$. If this problem can understood further, SSA can be used at a replacement ratio of 100wt% and the amount of useable SSA will dramatically increase.

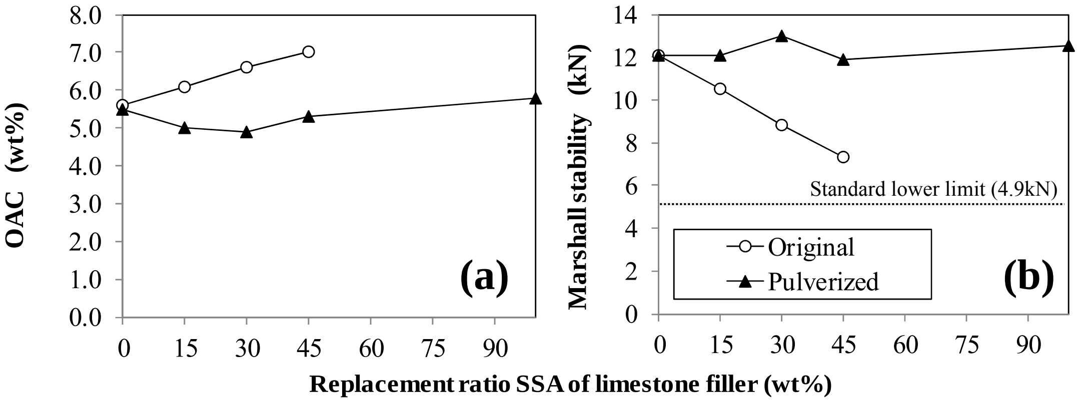


Figure 2. Relation between replacement ratio SSA and Optimum Asphalt content(a), Marshall stability(b)

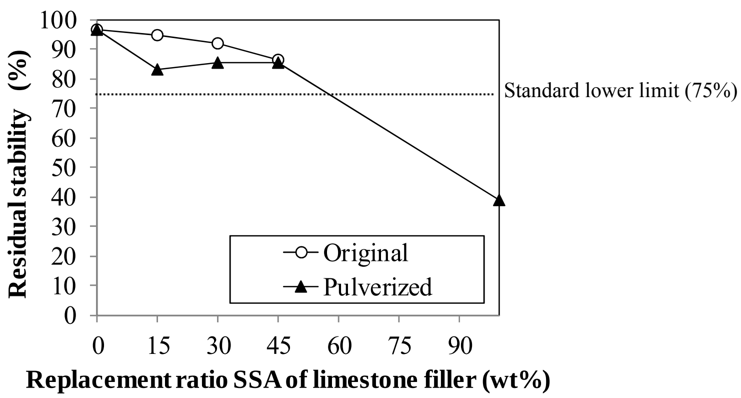


Figure 3. Relation between replacement ratio SSA and Residual stability

UTILIZATION AS BASE COURSE MATERIAL

Method. In this study, the authors proposed that SSA and fresh concrete be mixed for use as a base course material. The productions process is shown in Figure 4. The authors assumed that returned concrete would be used because fresh concrete is expensive. Returned concrete is concrete that is returned to a ready-mixed concrete plant, not unloaded at a construction site. This waste is produced at 1,500,000-2,000,000 tons per year in Japan. Assumed mix proportions of the returned concrete are shown in Table 3. This concrete design strength is 21N/mm^2. The authors assume that returned concrete is mixed in a drum mixer and left for 30 minute. The mixture is made by mixing SSA with this returned concrete before it sets. The two standard mixtures had on added 15wt% and 30wt% of SSA respectively. Simply adding SSA will not mix well into the returned concrete so water was added to the SSA at a moisture content of 135%. However, when Pulverized SSA was mixed at this moisture content and a ratio of 30wt%, serious segregation arose in the mixture. Thus moisture content in Pulverized SSA was reduced to 65%. This is what was set as the Flow property in the flow test (Table 1).

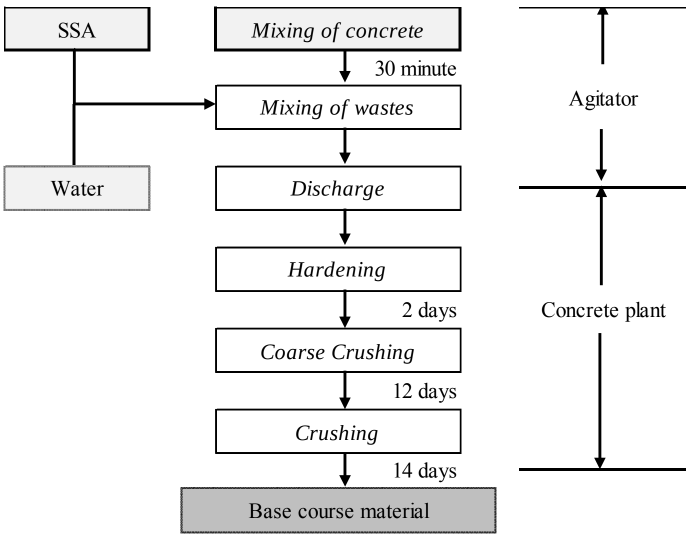


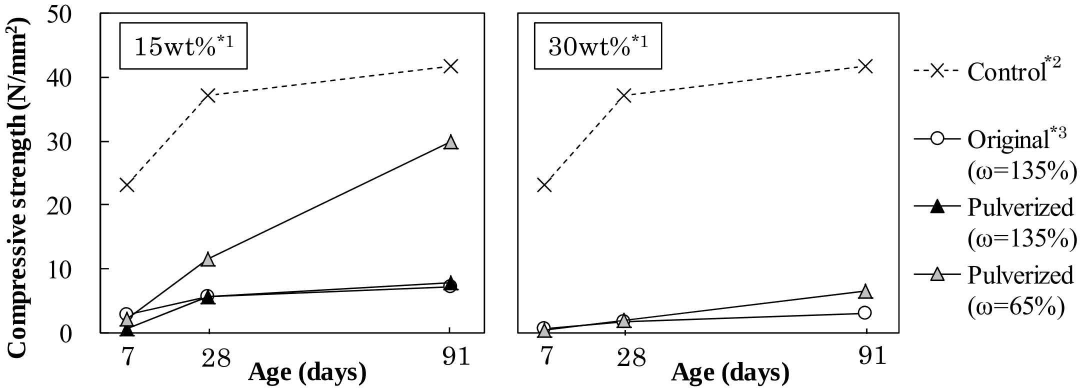
Figure 4. Method of using SSA and returned concrete as base course material

Table 3. Mix proportions of returned concrete

Maximum size (mm)	Slump (cm)	W/C (%)	Air content (%)	s/a (%)	Unit content (kg/m^3)				
					W	C	S	G	Admix.
25	8	59.5	4.5	43.5	158	266	830	1106	2.66

Compressive strength tests (JIS A 1108: 2010) were performed on φ100×200mm specimens at age 7, 28, and 91 days for understanding the property of solidified mixtures. The applicability of crushed mixtures as base course material were judged by Sieve analyses (JIS A1102: 2010), Compacting tests (JIS A1210: 2010), and Modified CBR tests (JIS A1211: 2010). With a supposed manufacturing time in a ready-mixed concrete plant, these tests were performed at the age of 28 days. In order to use crushed mixtures as sub-base course material, the Modified CBR value must be more than 30%.

Results and discussion. The compressive strength of solidified mixtures is shown in Figure 5. Combining SSA to returned concrete results in lower compressive strength. With, the same moisture content, the compressive of Pulverized SSA decreased comparable to that of Original SSA. However, with Pulverized SSA mixed at moisture content of 65%, compressive strength was improved at age 28 days and 91 days. Therefore compressive strength is decided by the unit water content of the mixture, not by the structure of the particles. This makes a significant difference when used as filler in asphalt mixtures. Grading curves of the crushed mixture before and after compaction are shown in Figure 6. In the case of low compressive strength, the mortar of crushed mixture fragmented by compaction. Thus Original SSA 30wt% and Pulverized SSA 30wt% deviated from the standard gradation of Crusher-Run Stone C-20 after compaction.



*1 15wt%, 30wt% : Added SSA weight versus fresh returned concrete weight.
*2 Control : Solidified only fresh returned concrete without SSA.
*3 ω : Moisture content of SSA including added water.

Figure 5. Compressive strength of the mixture using SSA and returned concrete

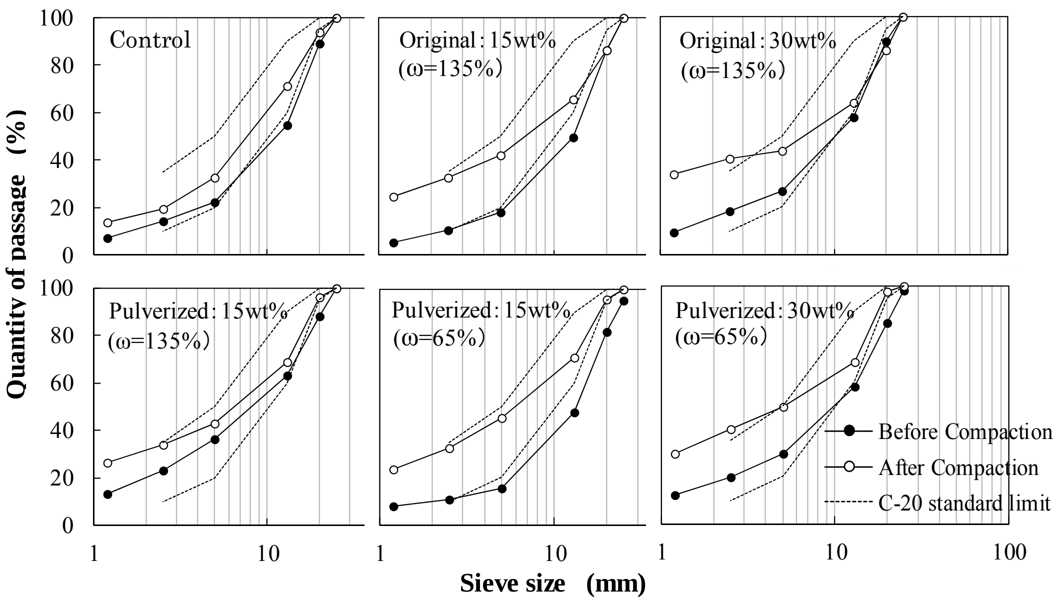


Figure 6. Grading curve of the mixture using SSA and returned concrete

The mixture's compressive strength and optimum water content had serious effects on compactibility. Compaction curves of the crushed mixture are shown in Fig. 7. For a mix ratio of 15wt%, the Original SSA mixture had a higher maximum dry density than only returned concrete. This is because of fragment particles densely filled in the voids of each specimen. This was expected when the Modified CBR of the mixture increased. However, with a mix ratio of 30wt%, the Original SSA mixture had a lower maximum dry density than only returned concrete. Furthermore, when over-compaction arose in the case of compaction at more than optimum water content, it was expected that bearing capacity would be extremely low. Over-compaction arose probably due to the following mechanisms: (1) As SSA with water is added to returned concrete, the water content in the mixture increases. Thus the mortar of the mixture becomes a porous structure. (2) Optimum water content of the crushing mixture increases with the porous mortar, which has a large amount of water it can absorb (Figure 7). (3) When the mortar is compacted, it is dehydrated as it is crushed, and the absorbed water is released. (4) An increase in released water leads to a rise in pore water pressure. Hence this condition arises in over-compaction.

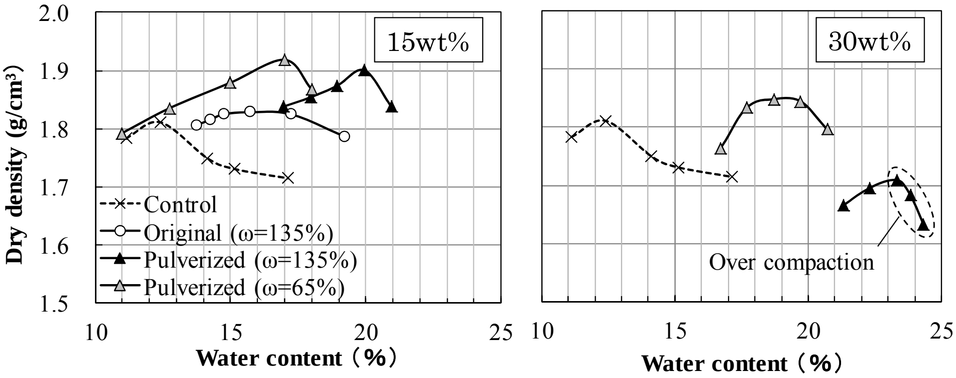


Figure 7. Compaction curve of the mixture using SSA and returned concrete

The modified CBR of the mixtures is shown in Figure 8. As expected, when the ratio was 15wt%, the mixture measured Modified CBR higher than the control (made from only returned concrete). However, if the ratio increased to 30wt% then over-compaction occurred. Consequently, the modified CBR of the mixture decreased tremendously. This problem can be overcome by the pulverization of SSA. Water content per unit of the mixture is decreased by the pulverization of SSA since the amount of water added to SSA to ensure miscibility is decreased. In this case, the mortar of the mixture is denser than an unprocessed SSA used case, and optimum water content is low (Figure 7). It is likely that water released by compaction will diminish. Therefore a mixture of Pulverized SSA will not over-compact if the ratio is increased to 30wt%. As a result, the Modified CBR of the mixture maintained a high value. The pulverization of SSA can be expected to further increase the amount of SSA usable in a mixture.

With this method, 63.8kg of original SSA can be used per 1 ton of returned concrete. It was calculated that about 96,000 tons* of original SSA could be used if it was applied to all of the returned concrete produced each year in Japan. (This is if original SSA is combined with the returned concrete at a moisture content of 135%, an outer percentage of 15wt% versus the returned concrete weight and assuming the concrete produced is 15,000,000 ton per year in Japan.) This amount can be increased to 181.8 kg if pulverized SSA is used. (This is if pulverized SSA is used at moisture content of 65% and combined at an outer percentage of 30wt% versus the concrete) Pulverization of SSA will increase amount of usable SSA.

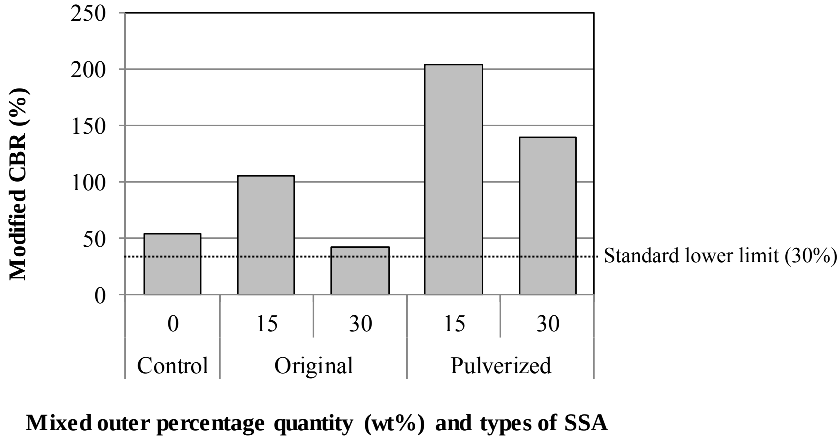


Figure 8. Modified CBR of the mixtures

LEACHING IN PRODUCTS THAT USE SSA

Method. It is important to ensure the safety of SSA products as well as ensure their quality. Therefore, environmental safety of the products was judged by a leaching test. Eluate from the asphalt mixture and the base course material were each prepared according to JIS K0058-1:2005 and the Japanese Leaching Test No.46 (JLT46). Common points in each methods are a batch test, L/S=10, and a leaching time of 6 hours. Constituent concentration of each elute was measured according to JIS K0102:2010.

Results and discussion. The results of the leaching tests are shown in Table 4. Leached concentrations of arsenic and selenium from the products using SSA were within the Japanese Standard. However, hexavalent chromium leaked from the base course material made by mixing SSA with concrete. Further studies are needed this problem.

Table 4. Leaching concentrations of recycled products

Element	Concentrations (mg/L)								Japanese Standard limits *4
	SSA		Asphalt mixture			Base course material			
	Original	Pulverized	Control*1 0%	Original*2 45%	Pulverized 100%	Control*1 0%	Original *3 30%	Pulverized 30%	
Cd	0.003	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01
Pb	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01
Hg	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0005
Cr(VI)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.11	0.14	<0.05
As	0.47	0.38	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.01
Se	0.048	0.039	<0.002	<0.002	<0.002	<0.002	0.007	0.003	<0.01
F	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.33	<0.20	<0.8
B	0.72	0.80	<0.10	<0.10	<0.10	<0.10	<0.1	<0.1	<1.0

*1 Control : Products made without using SSA.
*2 Types of SSA used and the replacement ratio to limestone.
*3 Types of SSA used and mixed outer percentage quantity to concrete.
*4 Asphalt mixture : JIS K 0058-1, Base course material and SSA : JLT46.

CONCLUSIONS

If SSA is pulverized, the properties of the pavement materials are improved and the amount of reusable material is increased. However, increased costs and the environmental impact must be examined. But this research revealed an important finding. The pulverizing of SSA was easier than mineral filler because SSA has a porous property. The amounts of leached concentrations of toxic substances from the SSA were not increased after pulverization. This result suggests that pulverization of SSA has a low impact level.

The findings of this study are outlined below.

1) Original SSA can be used as a replacement for limestone as filler in an asphalt mixture up to a replacement ratio of 45wt%.

2) When using pulverized SSA as a filler in an asphalt mixture, the residual stability degrades but the overall properties of the asphalt mixture improve greatly.

3) When making concrete that is a mixture of original SSA and returned concrete at a ratio of 15wt% original SSA, high quality modified CBR can be obtained. However if the ratio is increased to 30wt% then over-compaction occurs and the modified CBR level decreases.

4) When using a combination of pulverized SSA and returned concrete the amount of water needed decreases. As a result of this, unlike original SSA, a ratio of up to 30wt% pulverized SSA can be added without over-compaction occurring and high modified CBR levels can be obtained.

5) Arsenic and Selenium leach from SSA but when the SSA is mixed with asphalt or fresh concrete, the leaching concentration decreases dramatically. However, if SSA is mixed with returned concrete, then measures must be taken to prevent the leaching of hexavalent chromium.

6) With the measure suggested in this study, 1,030,000 tons of original SSA can be used annually as filler for asphalt mixture. When original SSA and returned concrete are mixed to create the base course material, 96,000 ton of SSA can be utilized each year. This amount can be increased two-fold if pulverized SSA is used.

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