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Durability of Recycled Asphalt Pavement Using Cementless Binders and Polymers

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Abstract

For increased recycling of waste asphalt concrete and reduced generation of CO_2, this study evaluated the stability and durability performance of cold-recycled asphalt that used cementless binders and polymers. For cementless binders, the present study used powder added with 80% ground granulated blast furnace slag (BFS) and fly ash, with the optimal mixture ratio derived from prior experiments. According to the test results, as the addition of polymers increased, Marshall stability increased but the flow values decreased. Abrasion resistance and dynamic stability (DS) were superior for specimens that used cementless binders and polymers than for those that used OPC. In particular, at room temperature of

20℃, deflection in the center of the test specimens decreased, and the deformation rate and DS were measured to be 0.0007 mm/min and 63,000 times/min, respectively.

Keywords: Durability, Recycled Asphalt, Cementless Binder, Polymer

1 Introduction

With considerable improvement in the quality of life thanks to industrial development in recent years, environmental pollution has emerged as one of the greatest problems facing humanity. In particular, the problem of industrial waste is a representative issue among environmental problems, and the disposal of construction waste has risen as a serious social problem.

While the amount of construction waste increases annually, natural aggregates in rivers have been nearly depleted at present, and the shortage of aggregates has reached critical levels. In addition, landfill sites in which the increasing construction waste can be buried likewise face serious scarcity, thus leading to expectations of future difficulties in the disposal of construction waste. The increase in diverse construction waste generated from construction sites and methods for the disposal of the ensuing waste both require attention.

On the other hand, with an increase in traffic volume in recent years, not only repair and maintenance constructions involving the asphalt concrete on provincial roads including national highways under the jurisdiction of diverse municipal and provincial governments but also replacement construction involving town gas, water supply, and sewage and waste water pipes have led to a steady increase in construction waste [1]. In this situation, various recycling studies are actively under way at the moment to allow construction waste to be used as industrial byproducts and to be recycled for environmental conservation and the efficient use of resources [2]. In particular, research on the recycling of waste asphalt concrete, which accounts for a considerable portion in the volume of construction waste, is necessary [3].

To increase the recycling rate of waste asphalt concrete, this study produced cold-recycled asphalt using recycled aggregates produced from waste asphalt concrete and with added polymers as performance-enhancing materials [4]. In addition, it evaluated the Marshall stability, flow values, abrasion resistance, and dynamic stability (DS) of the composites produced to confirm their durability performance.

2 Materials and testing methods

Waste asphalt concrete. As for the aggregates for the cold-recycled asphalt composites, waste asphalt concrete-recycled aggregates produced by G-company in South Korea were solely used.

Cementless binder. As for the cementless binders for the cold-recycled asphalt used in this study, the optimal mixture ratio derived from prior experiments was used, as presented in Table 1. The components were enhanced, mixed thoroughly, and then used. The cementless binders mixed included 56.3% CaO, and their chemical compositions are given in Table 2.

Table 1. Optimal mixture of cementless binders

Materials	Blast Furnace Slag	High-Calcium Fly Ash	Desulfurization Gypsum	Quick Lime	Slaked Lime	Superplasiticizer
Mixture rate	60%	20%	6%	8%	6%	0.002%

Table 2. Chemical compositions of cementless binders

Chemical compositions (%)	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	TiO_2	Na_2O	SO_3
	20.1	2.8	9.4	56.3	2.5	0.5	0.5	0.2	3.8

Polymer. As for the polymers used in this study, synthetic rubber latex (SBR) was employed, and the adhesive strength, tensile strength, flexural strength, wear resistance, and water tightness improved considerably when the rubber latex was added to the asphalt mixtures. The SBR used was a white liquid solution, and the results of a material analysis are given in Table 3.

Table 3. Properties of polymer (SBR)

Viscosity (Engler degree, 25℃)	pH (25℃)	Solid content (%)
62.0	9.86	46.15

Mixtures of recycled asphalt. To evaluate the Marshall stability and durability performance of cold-recycled asphalt using the cementless binders and polymers, cold-recycled asphalt was mixed in mixing water according to the addition conditions of the polymers, as presented in Tables 4 and 5.

Table 4. Recycled asphalt mixtures according to the addition of polymers

Mix No.	Filler	Mixing weight (wt.%)						
		Aggregate			Filler	Emulsifier	SBR polymer	Water
		13~25mm	8~13mm	≤8mm				
I-1	Cementless binders	55	28	13	4	1.5	-	3.5
I-2		55	28	13	4	1.5	0.13	3.37
I-3		55	28	13	4	1.5	1.17	2.33

Table 5. Recycled asphalt mixtures according to the addition of cementless binders and polymers

Mix No.	Filler	Mixing weight (wt.%)						
		Aggregate			Filler	Emulsifier	SBR polymer	Water
		13~25mm	8~13mm	≤8mm				
II-1	OPC	55	28	15	2	1.5	-	3.5
II-2	Cementless binders	55	28	13	4	1.5	0.13	3.37

Marshall stability and flow test. Marshall stability represents the resistance where the mixtures flowed or developed undular deformation at high temperatures due to the traffic load, and it was measured according to ASTM D 6927 “Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures [5].”

Abrasion resistance test. As for wear resistance tests in the present study, Cantabro loss tests were conducted to measure the degree to which aggregates broke off from both waste asphalt concrete and cold-recycled asphalt using cementless binders and polymers. Devised at the University of Cantabria in Spain, the Cantabro loss test consists of placing Marshall test specimens in a Los Angeles machine, turning the tester 300 times without using steel balls, and measuring the ensuing weight loss rates. Measurements for Cantabro tests of cold-recycled asphalt in the present study were made according to KS F 2492 “Standard Test Method of Cantabro Test for Porous Asphalt Mixtures,” and the loss rates were calculated using the equations below.

$$\text{Cantabro loss rate}\,(\%) = \frac{A - B}{B} \times 100 \quad (1)$$

Where, A: mass (g) of the specimens before the tests
B: mass (g) of the specimens after the tests

Dynamic stability (DS) test. In this study, the DS of cold-recycled asphalt using cementless binders and polymers was evaluated by measuring the amount of deformation in the test specimens according to KS F 2374 "Standard test method for wheel tracking of asphalt mixtures." As for the production of the specimens, the compacting device in Fig. 1 was used to produce specimens with dimensions of 300×300×65 mm. For the specimens produced, a wheel tracking tester was used to apply a 686 N traffic load, the normal deformation of the mixtures was measured, and the results were comparatively analyzed. When producing one specimen, approximately 10 kg of the mixture was placed on a preheated compaction plate and subjected to pressure with a roller. The wheel for the wheel tracking test conducted on the specimens was made of steel with a diameter of 200 mm, a width of 53 mm, a travel distance of 200 mm, and a velocity of 30 trips/min (0.5 Hz). The test temperature was 60℃ in consideration of the surface temperature of asphalt pavement during the hottest times in summer. DS and the final rut depth were obtained from the amount of deformation at 45 minutes and 60 minutes, respectively, after starting measurements with the wheel load applied.

$$\text{Dynamic stability (DS)} = 42 \times \frac{t_2 - t_1}{d_2 - d_1} \times C(times/mm) \quad (2)$$

Where, d_1: amount of deformation (mm) at t_1 (45 minutes in general)
d_2: amount of deformation (mm) at t_2 (60 minutes in general)
C: calibration coefficient when a variable-speed drive tester with cranks was used = 1.0

$$\text{Rate of deformatio (RD)} = \frac{d_{60} - d_{45}}{15} (mm/\text{min}) \quad (3)$$

Where, d_{60}: amount of deformation (mm) at 45 minutes
d_{45}: amount of deformation (mm) at 60 minutes

(a) Mixing (b) Weigh Measurement

(c) Compaction (d) Complete Production

Figure 1. Production of wheel tracking test specimens of cold-recycled asphalt

Figure 2. An overview of DS tests of cold-recycled asphalt (wheel tracking)

3 Result and discussion

Marshall stability and flow. Figure 3 shows the characteristics according to the addition conditions of cementless binders and polymers, and, as the amount of SBR polymers used was increased, Marshall stability increased as well [6]. This tendency stemmed from the following: SBR resin polymers that had become functional polymer composites formed network structures among the aggregates and filled the pores, thus increasing the adhesive strength and tensile strength; they not only suppressed expansion cracks but also were spread equally within the asphalt mixtures, thus adding elasticity and improving the heat resistance, low temperature resistance, and strength of the binders (asphalt emulsions).

Figure 4 shows the results of flow value tests of the specimens, and the measurements were approximately 20.5~24.3 mm. With the addition of SBR polymers, a tendency opposite that of the Marshall stability was observed, and, as the Marshall stability increased, the bonding strength within recycled asphalt and the adhesive force of the aggregates improved, thus reducing the flow values.

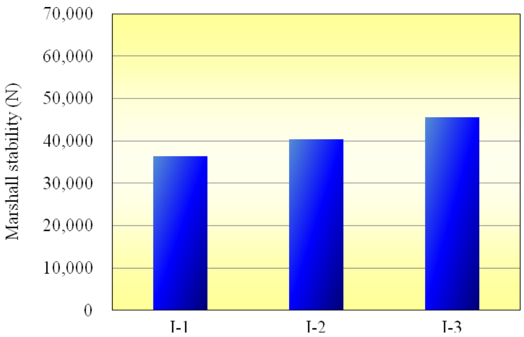


Figure 3. Marshall stability of cold-recycled asphalt according to the mixing SBR polymer

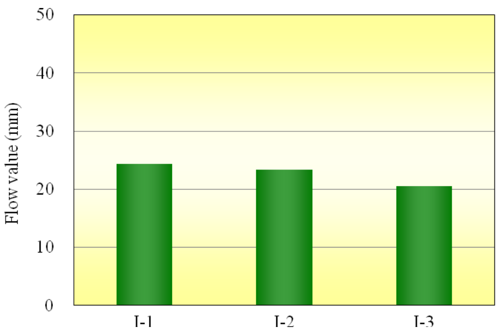


Figure 4. Flow values of cold-recycled asphalt according to the mixing SBR polymer

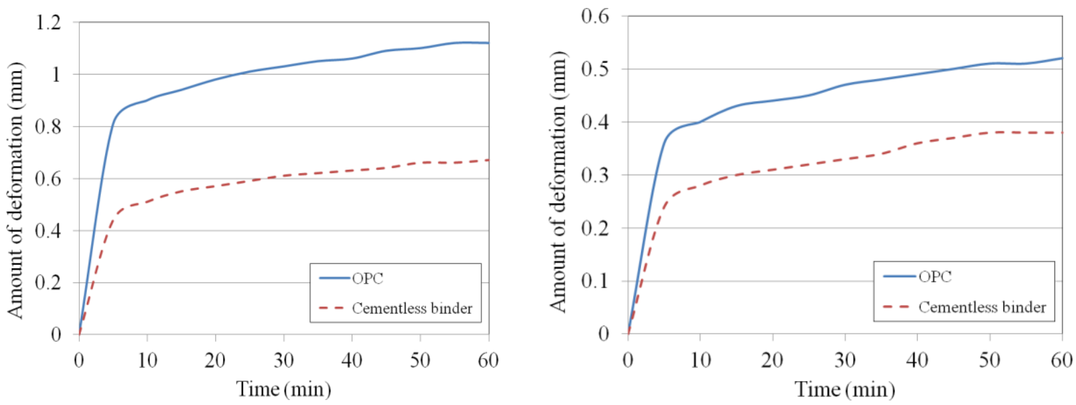
Abrasion resistance. The mass loss rate of the cold-recycled asphalt test specimens was 17~18%, and the mass decrease rates decreased, albeit minutely, for mixtures using cementless binders as fillers and with added SBR polymers, thus exhibiting outstanding wear resistance.

Although evaluation standards for the wear resistance of cold-recycled asphalt have not been stipulated, when compared to "20% or below," the Cantabro loss test quality standard for porous asphalt pavement, cold-recycled asphalt exhibited outstanding wear resistance.

Dynamic stability (DS). To evaluate the DS of cold-recycled asphalt under room temperature and high temperature conditions, the present study conducted evaluations at 20℃ and 60℃. The amount of deformation according to the test time is shown in Figure 5 and Tables 6~7, and an overview of the test specimens after the evaluations is provided in Figure 6. When wheel tracking evaluations were performed according to the mixing conditions and temperature conditions, under all mixing conditions, deflection in the center tended to increase dramatically up to approximately 5 minutes, after which deflection increased gradually up to 60 minutes, and finally converging at certain values. The mixture where OPC had been used as the filler (II-1) developed more deformation than the mixture using cementless binders (II-2), regardless of the temperature conditions, thus showing that the use of cementless binders as fillers led to outstanding resistance to deformation [6].

In addition, regarding the amount of deformation according to the temperature during the evaluations, the 60℃ condition was an adverse condition with a temperature higher than room temperature, exhibiting a high amount of deformation. This seems to be due to softening of the asphalt emulsions at high temperatures, thus leading to an increase in the amount of deformation.

As for DS, between 45 minutes and 60 minutes after the initiation of measurements, when the amount of deformation became nearly consistent, the amount of deformation generated for 15 minutes was obtained and expressed as the rate of deformation (RD). Here, evaluations were conducted by calculating the number of turns of the wheel needed for 1 mm of deformation. According to the results of inspections, under the 60℃ condition, the amount of deformation and DS were identical, 21,000 times/mm, under all mixing conditions; under the 20℃ standard, mixture II-2 exhibited twofold higher DS relative to that of mixture II-1. When the experimental temperature conditions were high, DS was identical regardless of the type of filler; however, under room temperature conditions, when cementless binders were used, the matrix of cold-recycled asphalt mixtures became dense, thus leading to outstanding DS [7]. However, under all mixing conditions and temperature conditions, 3,000 times/mm, the surface standard value for DS was exceeded and consequently the resistance to plastic deformation was outstanding.



(a) Temperature condition : 60℃ (b) Temperature condition : 20℃

Figure 5. Time-deformation properties of cold-recycled asphalt by Dynamic stability test

Table 6. Dynamic stability result of cold-recycled asphalt (60℃)

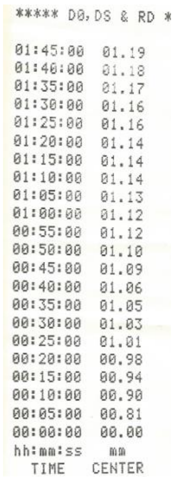
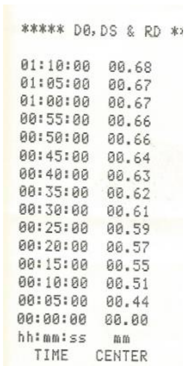
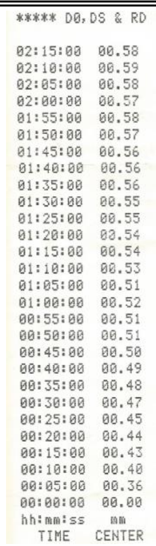
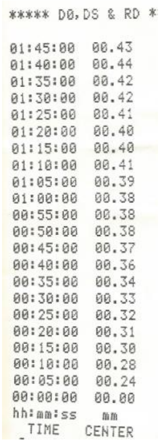
Time (min)	Amount of deformation (mm)		Date sheet	
	II-1	II-2		
0	0.00	0.00	 ***** D0,DS & RD * 01:45:00 01.19 01:40:00 01.18 01:35:00 01.17 01:30:00 01.16 01:25:00 01.16 01:20:00 01.14 01:15:00 01.14 01:10:00 01.14 01:05:00 01.13 01:00:00 01.12 00:55:00 01.12 00:50:00 01.10 00:45:00 01.09 00:40:00 01.06 00:35:00 01.05 00:30:00 01.03 00:25:00 01.01 00:20:00 00.98 00:15:00 00.94 00:10:00 00.90 00:05:00 00.81 00:00:00 00.00 hh:mm:ss mm TIME CENTER	 ***** D0,DS & RD * 01:10:00 00.68 01:05:00 00.67 01:00:00 00.67 00:55:00 00.66 00:50:00 00.66 00:45:00 00.64 00:40:00 00.63 00:35:00 00.62 00:30:00 00.61 00:25:00 00.59 00:20:00 00.57 00:15:00 00.55 00:10:00 00.51 00:05:00 00.44 00:00:00 00.00 hh:mm:ss mm TIME CENTER
5	0.81	0.44		
10	0.90	0.51		
15	0.94	0.55		
20	0.98	0.57		
25	1.01	0.59		
30	1.03	0.61		
35	1.05	0.62		
40	1.06	0.63		
45	1.09	0.64		
50	1.10	0.66		
55	1.12	0.66		
60	1.12	0.67		
Rate of deformation	0.0020mm/min	0.0020mm/min		
Dynamic stability	21,000times/min	21,000times/min	II-1	II-2

Table 7. Dynamic stability result of cold-recycled asphalt (20℃)

Time (min)	Amount of deformation (mm)		Date sheet	
	II-1	II-2		
0	0.00	0.00	 ***** D0,DS & RD 02:15:00 00.58 02:10:00 00.59 02:05:00 00.58 02:00:00 00.57 01:55:00 00.58 01:50:00 00.57 01:45:00 00.56 01:40:00 00.56 01:35:00 00.56 01:30:00 00.55 01:25:00 00.55 01:20:00 00.54 01:15:00 00.54 01:10:00 00.53 01:05:00 00.51 01:00:00 00.52 00:55:00 00.51 00:50:00 00.51 00:45:00 00.50 00:40:00 00.49 00:35:00 00.48 00:30:00 00.47 00:25:00 00.45 00:20:00 00.44 00:15:00 00.43 00:10:00 00.40 00:05:00 00.36 00:00:00 00.00 hh:mm:ss mm TIME CENTER	 ***** D0,DS & RD * 01:45:00 00.43 01:40:00 00.44 01:35:00 00.42 01:30:00 00.42 01:25:00 00.41 01:20:00 00.40 01:15:00 00.40 01:10:00 00.41 01:05:00 00.39 01:00:00 00.38 00:55:00 00.38 00:50:00 00.38 00:45:00 00.37 00:40:00 00.36 00:35:00 00.34 00:30:00 00.33 00:25:00 00.32 00:20:00 00.31 00:15:00 00.30 00:10:00 00.28 00:05:00 00.24 00:00:00 00.00 hh:mm:ss mm TIME CENTER
5	0.36	0.24		
10	0.40	0.28		
15	0.43	0.30		
20	0.44	0.31		
25	0.45	0.32		
30	0.47	0.33		
35	0.48	0.34		
40	0.49	0.36		
45	0.50	0.37		
50	0.51	0.38		
55	0.51	0.38		
60	0.52	0.38		
Rate of deformation	0.0013mm/min	0.0007mm/min		
Dynamic stability	31,500times/min	63,000times/min	II-1	II-2

4 Conclusions

The durability properties of recycled asphalt mixtures produced with waste asphalt concrete and polymer (SBR) are as follows.

(1) As cementless binders and polymers were added, the adhesive strength and tensile strength among aggregates increased, thus suppressing expansion cracks and improving the Marshall stability of recycled asphalt. However, in contrast to stability, the flow values decreased.

(2) The mass loss rate of cold-recycled asphalt was 17-18%, and the abrasion resistance was confirmed to be outstanding when SBR polymers were added.

(3) When cementless binders and polymers were added at 20℃, the deformation rate of the specimens was measured to be approximately 0.0007 mm/min, and DS was approximately doubly superior. Consequently, when cementless binders and polymers are added to recycled asphalt produced by recycling waste asphalt concrete, it will be possible to secure outstanding durability.

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