Experimental Study on Mix Design Methods of Hot-laid Bituminous Mixtures

— Effects of Very Fine Particle Size Filler and Mixing Temperature on the Results of Marshall Test* —

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Abstract

When paving with bituminous mixtures in fields, they should be kept in the maximum temperature ranges, in which bitumen is not excessively degraded.

The purposes of heating bituminous materials are to improve the adhesive property of bitumen to aggregates and thereby to enhance the workability of the bituminous mixtures, because the lower viscosity of bituminous materials makes it wet well and adhere to the surfaces of the aggregate particles in a shorter time.

In ASTM, the adequate viscosities are said to be obtained by the specified mixing and compaction times of 85±10sec and 140±15sec respectively.

These are the working temperatures of the mixtures estimated from bitumen itself. An adequate working temperature, however, as it varies with many working conditions, cannot be determined simply by the viscosity of the working bitumen ; for example, the adequate working temperature varies with the kinds, quality and amounts of bitumen and filler as well as with the particle sizes of other aggregates.

Consequently, it became necessary to examine and determine the adequate mixing temperature of the bituminous mixture at which bitumen is not hardened unreasonably.

Using the undersizes of filler $37\mu m$ and $74\mu m$ sieves and changing F/A from 0 to 2.0, this study first carried out a series of Saybolt Furol viscosity tests and found out that the adequate mixing temperatures were 144°C and 180°C, followed by Marshall tests to clarify the effects of bitumen in the mixtures.

1. INTRODUCTION

In general, the mix design of asphaltic mixtures is designed by using the standard particle size specified in the guideline, and the Marshall tests are performed by changing the amount of asphalt to determine the design amount of asphalt.

Since the amount of filler bitumen and the asphalt to filler ratio in filler bitumen are important for wear resistant asphaltic mixtures, filler is removed from the aggregate particle sizes, and is distributed to each particle size. In other words, the difference between the

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widely used mix design method based on the guideline and that of the filler bitumen method in whether filler is included in the particle sizes of the aggregate or in whether filler is removed from them to make the F/A ratio constant.

The filler bitumen method investigated in this study moreover develops this concept, and the G/S ratio is constant, considering asphalt mortar (to be abbreviated below as asmor) is a binding material of asphalt concrete (to be abbreviated below as ascon).

In the mix design calculation of the guideline method, the change in the asphalt contents leads to the change in the ratio of asphalt to other aggregates, on the other hand, the filler bitumen method the change in the asphalt contents results in the change in the ratio of filler bitumen to other aggregates with F/A being constant.

Accordingly, the results of the Marshall tests using specimens prepared by these two methods with the binder contents changed indicate that the structure of the result mixture consisting of the aggregate containing filler with extremely wide surface area and the adhesive asphalt differs from that consisting of the filler-removed aggregate and the adhesive filler bitumen.

2. PROCEDURE

2. 1 A New Expression Method of the Compacted Asphaltic Mixtures.

The compacted asphalt mixture is almost composed of three elements; void, asphalt and aggregate. They are diversely distributed and form asphaltic mixtures. The ratios of the three elements can be clearly expressed by the model. Their volumes and weights can be defined as shown in the Figure 1. Percentage of air voids (V_v) means the volu me percentage of void accounting for the whole volume. Degree of saturation (V_{fa}) means the volume percentage of asphalt accounting for the volume of void plus asphalt, indicating the percentage of asphalt filling the gaps of the aggregate from the viewpoint of the asphalt mixes as a whole. Voids of mineral aggregate (V_{ma}) means the volume ratio of asphalt plus void after deducting aggregate from the whole volume.

Specific gravity is the ratio of the unit weight of a substance to that of water and dimensionless, with water under 1 atmospheric pressure at room temperature being standard. These are the basic ways of thinking.

In this study, however, asmor is considered to be the binding materials of ascon and the relation between V_{fm} and V_{mg} was investigated. The voids of filled with mortar (V_{fm}) means the percentage of asmor filling the gaps of the aggregate, whereas the voids of mineral gravel (V_{mg}) means the volume ratio of whole ascon minus gravel to asmor plus void.

These symbol V_v, V_{ma}, V_{fa}, V_{fm}, V_{mg} lead to the following equation, with the results of calculation are shown in the Table 1. 2.

2. 2 A New Model and Calculation Method

In the general case, we have

$$V_v = \left(\frac{V_v}{V} = \frac{V - V'}{V} = 1 - \frac{V'}{V} = 1 - \frac{D_m}{D_t}\right) \times 100(\%)$$

$$V_{fa} = \left[\frac{V_A}{V_V \times V_A} = \frac{V_A / V}{(V_V + V_A)/V} = \frac{V_a}{V_v + V_a} = \frac{V_a}{V_{ma}}\right] \times 100(\%)$$

$$V_{ma} = \frac{V_V + V_A}{V} = V_v + V_a (\%)$$

$$V_a = \frac{W_a \times D_m}{D_a / \gamma_\omega} (\%)$$

, where,

D_m : density of asphaltic mixtures (g/㎤)

D_t : maximum theoretical density (g/㎤)

V_a : percentage of asphalt by volume (%)

W_a : percentage of asphalt by weight (%)

D_a : density of asphalt (g/㎤)

γ_ω : density of water (g/㎤≒1)

Putting

$$D_t = \frac{100}{W_a/D_a + 1/\gamma_w \Sigma W_i / G_i}$$

, where W_i : percentage of various aggregate (%), G_i : density of various aggregate

In the filler bitumen method case, the general case to be identical, we can write

$$V_{fm} = \left(\frac{V_A + V_F + V_S}{V_V + V_A + V_F + V_S} = \frac{V_m}{V_{mg}} = \frac{V_{mg} - V_v}{V_{mg}}\right) \times 100(\%)$$

$$V_{mg} = \frac{V_V + V_A + V_F + V_S}{V} = V_v + V_m (\%)$$

$$V_m = \left(\frac{100}{D_t} - \frac{W_g}{G_g}\right) \times D_m (\%)$$

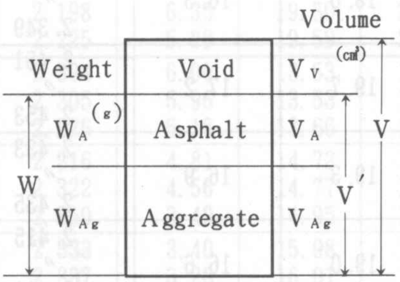

Fig. 1 General Case

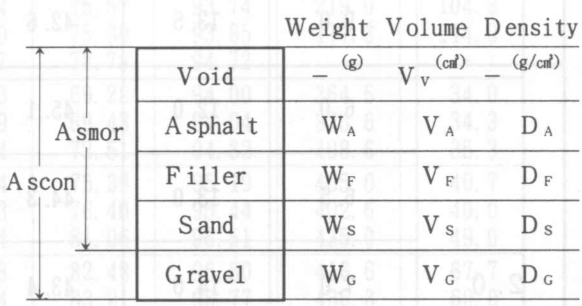

Fig. 2 FB Method Case

3. RESULTS AND DISCUSSION

3-1 Marshall Test

In this study, the purpose of Marshall test is both to the determination of the most suitable amount of asphalt to it's mix designs of aggregate and to gain the mix designs of

Table. 1 Glance Through with the Results of Tests (Asphalt Mortar)

Ratio	Asphalt	Filler	Sands S (%)			(g/cm³)
F/A	A (%)	F (%)	(mm) 2.5~0.6	(mm) 0.6~0.3	(mm) 0.3~0.15	Dt
1.0	7.0	7.0	47.3	20.6	18.1	2.414 ″ 2.416
	8.0	8.0	46.2	20.2	17.6	2.379 ″ 2.381
	8.5	8.5	45.7	19.9	17.4	2.362 ″ 2.364
	9.0	9.0	45.1	19.7	17.2	2.346 ″ 2.347
	9.5	9.5	44.6	19.4	17.0	2.329 ″ 2.331
1.5	6.0	9.0	46.8	20.4	17.8	2.450 ″ 2.452
	7.0	10.5	45.4	19.8	17.3	2.415 ″ 2.416
	7.5	11.2	44.7	19.5	17.1	2.397 ″ 2.399
	8.0	12.0	44.0	19.2	16.8	2.380 ″ 2.382
	9.0	13.5	42.6	18.6	16.3	2.347 ″ 2.349
2.0	6.0	12.0	45.1	19.7	17.2	2.451 ″ 2.453
	6.5	13.0	44.3	19.3	16.9	2.433 ″ 2.435
	7.0	14.0	43.4	19.0	16.6	2.415 ″ 2.418
	7.5	15.0	42.6	18.6	16.3	2.398 ″ 2.400
	8.0	16.0	41.8	18.2	16.0	2.381 ″ 2.383

Upper= F 74μm, M·T180℃
Middle= F 74μm, M·T144℃
Under= F 37μm, M·T180℃

Density Tests						Marshall Tests	
(g/cm³) Dm	(%) Vv	(%) Va	(%) Vma	(%) Vfa	(%) Vfm	(Kg) St	(1/100㎝) Fl
2.214	8.29	15.16	23.45	64.67	91.72	173.6	24.7
2.211	8.41	15.14	23.55	64.30	91.59	143.0	30.0
2.231	7.66	15.28	22.94	66.62	92.34	142.0	30.0
2.253	5.30	17.64	22.93	76.91	94.70	212.0	33.7
2.227	6.39	17.43	23.82	73.18	93.61	160.0	43.3
2.262	5.00	17.71	22.71	77.99	95.00	173.0	49.3
2.241	5.12	18.64	23.76	78.44	94.88	196.0	55.0
2.242	5.08	18.65	23.73	78.59	94.92	214.6	59.3
2.253	4.70	18.74	23.43	79.96	95.30	209.3	68.7
2.271	3.17	20.00	23.17	86.34	96.83	259.6	62.7
2.226	5.12	19.60	24.72	79.31	94.88	212.6	72.3
2.227	5.11	19.61	24.72	79.32	94.89	184.0	82.5
2.188	6.05	20.34	26.39	77.06	93.95	172.6	79.7
2.178	6.48	20.25	26.73	75.74	93.52	144.0	74.3
2.190	6.05	20.36	24.41	77.09	93.95	142.3	98.0
2.229	9.02	13.09	22.11	59.20	90.98	257.0	22.0
2.228	9.06	13.08	22.14	59.08	90.94	203.0	28.7
2.251	8.20	13.21	21.41	61.72	91.80	226.3	27.0
2.275	5.80	15.58	21.38	72.88	94.20	289.3	31.7
2.283	5.47	15.64	21.10	74.10	94.53	278.3	42.7
2.299	4.84	15.75	20.59	76.48	95.16	283.0	42.3
2.283	4.76	16.75	21.51	77.89	95.24	297.6	56.7
2.287	4.59	16.78	21.37	78.53	95.41	302.0	63.0
2.325	3.01	17.15	20.16	85.00	96.99	326.0	61.0
2.263	4.92	17.71	22.63	78.28	95.08	274.0	69.0
2.261	5.00	17.70	22.70	77.97	95.00	271.6	68.0
2.283	4.16	17.87	22.03	81.13	95.84	260.0	78.3
2.200	6.26	19.37	25.64	75.57	93.74	219.0	104.3
2.198	6.35	19.30	25.70	75.30	93.65	177.3	114.0
2.225	5.28	19.59	24.87	78.78	94.72	–	–
2.304	6.00	13.53	19.53	69.28	94.00	364.6	34.0
2.305	5.96	13.53	19.49	69.43	94.04	375.6	34.3
2.326	5.18	13.66	18.84	72.51	94.82	408.6	35.3
2.316	4.81	14.73	19.54	75.39	95.19	405.0	40.7
2.322	4.56	14.77	19.33	76.40	95.44	402.6	40.0
2.350	3.49	14.95	18.44	81.06	96.51	435.0	49.0
2.333	3.40	15.98	19.38	82.48	96.60	416.6	67.7
2.337	3.23	16.01	19.24	83.21	96.77	436.3	60.0
2.342	3.14	16.04	19.18	83.62	96.86	409.3	73.7
2.305	3.88	16.92	20.79	81.35	96.12	382.0	79.3
2.324	3.09	17.06	20.14	84.68	96.91	375.0	81.3
2.300	4.17	16.88	21.05	80.20	95.83	310.3	90.7
2.256	5.25	17.66	22.91	77.08	94.75	276.0	110.0
2.285	4.03	17.89	21.92	81.60	95.97	287.6	121.3
2.263	5.04	17.71	22.75	77.86	94.96	–	–

Table. 2 Glance Through with the Results of Tests (Asphalt Concrete)

Ratio	Asphalt	Filler	Gravels G(%)		Sands S (%)			Asp in	
F／A	A (%)	F (%)	(mm) 13~5	(mm) 5~2.5	(mm) 2.5~0.6	(mm) 0.6~0.3	(mm) 0.3~0.15	Asmor A(%)	(g/cm³) Dt
1.0	4.0	4.0	25.8	24.8	22.8	9.9	8.7	8.1	2.533 ″ 2.534
	4.5	4.5	25.5	24.5	22.5	9.8	8.6	9.0	2.514 ″ 2.514
	5.0	5.0	25.2	24.3	22.3	9.7	8.5	9.9	2.494 ″ 2.495
	5.5	5.5	25.0	24.0	22.0	9.6	8.4	10.8	2.476 ″ 2.477
	6.0	6.0	24.7	23.7	21.8	9.5	8.3	11.6	2.458 ″ 2.459
1.5	3.0	4.5	25.9	24.9	22.9	10.0	8.7	6.1	2.573 ″ 2.573
	4.0	6.0	25.2	24.2	22.3	9.7	8.5	7.9	2.533 ″ 2.534
	4.5	6.7	24.9	23.9	22.0	9.6	8.4	8.8	2.514 ″ 2.515
	5.0	7.5	24.5	23.6	21.6	9.4	8.3	9.6	2.495 ″ 2.496
	6.0	9.0	23.8	22.9	21.0	9.2	8.0	11.3	2.458 ″ 2.459
2.0	3.0	6.0	25.8	24.7	22.5	9.8	8.6	6.1	2.573 ″ 2.574
	3.5	7.0	25.1	24.1	22.1	9.7	8.5	6.9	2.553 ″ 2.554
	4.0	8.0	24.7	23.7	21.8	9.5	8.3	7.8	2.534 ″ 2.535
	4.5	9.0	24.3	23.3	21.4	9.0	8.2	8.6	2.514 ″ 2.516
	5.0	10.0	23.8	22.9	21.0	9.2	8.0	9.4	2.495 ″ 2.497

Upper= F 74μm, M·T180℃
Middle= F 74μm, M·T144℃
Under= F 37μm, M·T180℃

Density Tests								Marshall Tests	
(g/cm³) Dm	(%) Vv	(%) Va	(%) Vma	(%) Vfa	(%) Vm	(%) Vmg	(%) Vfm	(Kg) St	(1/100m) Fl
2.359	6.87	9.23	16.10	57.34	49.05	55.91	87.72	431.6	·18.0
2.362	6.75	9.24	15.99	57.80	49.11	55.86	87.91	356.3	22.3
2.360	6.87	9.24	16.11	57.36	49.03	55.90	87.71	345.0	25.0
2.379	5.37	10.48	15.85	66.11	50.65	56.02	90.41	482.6	17.0
2.393	4.81	10.54	15.35	68.64	50.95	55.77	91.37	398.6	23.7
2.395	4.73	10.55	15.28	69.02	50.99	55.69	91.57	369.0	24.3
2.412	3.29	11.80	15.09	78.21	52.62	55.90	94.12	515.6	21.0
2.411	3.33	11.80	15.13	77.99	52.59	55.92	94.05	452.6	28.0
2.419	3.05	11.84	14.89	79.53	52.73	55.78	94.54	418.0	31.3
2.406	2.83	12.95	15.78	82.08	53.67	56.50	95.00	501.3	34.0
2.403	2.95	12.93	15.88	81.44	53.61	56.56	94.79	441.0	33.0
2.432	1.82	13.09	14.91	87.81	54.21	56.03	96.76	463.3	38.3
2.385	2.69	14.00	16.69	83.87	54.67	57.37	95.31	460.0	38.0
2.394	2.33	14.06	16.39	85.80	54.88	57.20	95.93	416.0	45.7
2.425	1.38	14.24	15.62	91.15	55.27	56.65	97.56	451.0	46.3
2.346	8.82	6.89	15.71	43.84	47.10	55.92	84.22	509.3	19.7
2.340	9.06	6.87	15.93	43.13	46.98	56.04	83.84	410.0	23.7
2.357	8.40	6.92	15.32	45.18	47.32	55.72	84.93	373.3	24.7
2.411	5.23	9.44	14.67	64.35	50.69	55.92	90.65	575.0	20.3
2.408	5.35	9.43	14.78	63.81	50.63	55.98	90.45	508.6	25.0
2.410	4.89	9.43	14.32	65.84	51.05	55.94	91.25	484.6	28.0
2.448	2.62	10.78	13.40	80.43	53.24	55.87	95.30	622.0	26.0
2.432	3.26	10.71	13.97	76.65	52.90	56.16	94.19	580.0	33.3
2.440	2.98	10.74	13.72	78.27	53.03	56.01	94.68	561.6	35.3
2.446	1.21	11.97	13.18	90.80	55.32	56.53	97.86	577.0	33.3
2.436	1.62	11.92	13.53	88.06	55.09	56.71	97.15	559.6	41.3
2.448	1.92	11.98	13.90	186.16	54.57	56.49	96.60	568.6	43.7
2.419	1.59	14.20	15.79	89.95	56.65	58.23	97.27	445.0	63.7
2.409	1.99	14.14	16.13	87.65	56.41	58.41	96.59	407.0	71.3
2.419	1.62	14.20	15.82	89.74	56.61	58.23	97.21	401.0	72.0
2.357	8.40	6.92	15.31	45.18	48.04	56.43	85.12	596.0	20.0
2.381	7.46	6.99	14.45	48.36	48.53	55.99	86.67	538.0	24.7
2.363	8.20	6.94	15.13	45.83	48.12	56.32	85.45	565.6	22.3
2.410	5.60	8.25	13.85	59.57	50.59	56.19	90.03	675.6	22:0
2.419	5.25	8.24	13.53	61.21	50.78	56.03	90.63	564.6	29.3
2.407	5.76	8.24	14.00	58.88	50.49	56.25	89.77	630.6	27.0
2.455	3.12	9.61	12.73	75.50	53.00	56.12	94.44	768.3	25.7
2.455	3.12	9.61	12.73	75.57	53.00	56.12	94.44	653.0	27.7
2.453	3.24	9.60	12.84	74.80	52.92	56.15	94.24	690.3	22.7
2.465	1.95	10.85	12.80	84.78	54.74	56.69	96.56	741.3	33.0
2.471	1.71	10.88	12.59	86.42	54.88	56.59	96.98	655.3	43.0
2.463	2.11	10.85	12.95	83.74	54.62	56.73	96.29	743.6	39.0
2.459	1.44	12.03	13.47	89.29	56.10	57.54	97.49	626.6	49.3
2.465	1.20	12.06	13.26	90.94	56.24	57.44	97.91	650.3	57.7
2.480	0.68	12.13	12.81	94.69	56.50	57.18	98.81	618.0	55.3

asphaltic mixtures. This paper were carried out with F/A values from 1.0 to 2.0 five kinds of binder content and prepared at least three specimens for each combination of aggregates and bitumen content. The results of measurement were averaged and subjected to calculation as described in the preceding sections (Table 1. 2).

3-2 Saybolt Furol Viscosity Test

This method is based on ASTM ; E 102-62 and capable of determinative of Saybolt Furol viscosity of bituminous materials at temperatures of 250, 275, 300, 325, 350, 400, and 450F (121, 135, 149, 163, 177, 204, and 232°C).

This study carried out using changing binder F/A value 0~2.0, and F 37*μm* and F 74*μm*. Their results are shawn in Figure 3.

3-3 Materials

Asphalt used for straight asphalt of 80/100. This characteristics are shown in Table 3. Aggregates used for sand and crushed rock. Their properties and mix design are shown in Table 4. Filler used for Kunnepu mineral powder ($G_{f74\mu}=2.714$, $G_{f37\mu}=2.734$).

3-4 Asphaltic Mixtures

For the compacted asphalt mixes, the most important factor is the amount of asphalt. There are four stages which appear continuously as the amount of asphalt changes.

Table. 3 Properties of Bituminous Materials

Penetration (25℃, 100g, 5sec)		93
Softening Point R & B (℃)		46.0
Penetration Index		-0.7
Ductility (cm)	5℃	6.0
	15℃	100over
Thin Film Oven (%)	Percent Loss in Mass	0.078
	Penetration Ratio	63.3
Loss-on -heating (%)	Percent Loss in Mass	0.0
	Penetration Ratio	91.3
Solubility in Carbon Tetrachloride (%)		99.8
Specific Gravity (25℃/25℃)		1.022

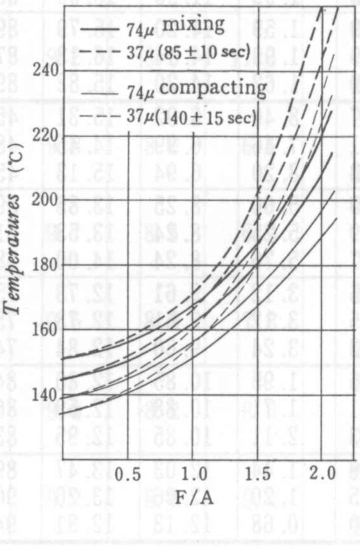

Fig. 3 Results of SFV Test

Table. 4 Mix Design and Properties of Materials

Place of Production	Kunnepu Crusher Rock		Tokoro Sand		Shari Sand
Particle Sizes	(mm) 13～5	(mm) 5～2.5	(mm) 2.5～0.6	(mm) 0.6～0.3	(mm) 0.3～0.15
Asphalt(%) Concrete	28	27	25	11	9
Asphalt(%) Mortar			55	24	21
Specific Gravity	2.713	2.702	2.654	2.702	2.763
Water(%) Absorption	0.57	0.67	1.12	1.03	0.96

3-5 Changes in Properties of Asphalt Mixes Associated with Change in Binder

In the first stage, the amount of asphalt is very small in comparison with those of aggregate particles and voids. Shortage of asphalt does not permit complete connection between the aggregate particles and asphalt. Breaking strength in the Marshall test is low and the corresponding deformation is also small.

In the second stage, the amount of asphalt increases gradually, the aggregate particles approach to each other, strong force acts between asphalt and air in the gaps, and thereby strong connection is formed. Breaking strength shows a maximum, but a fairly great amount of air void still remains.In addition, D_m becomes greater than that in the first stage, but does not show a maximum. In the third stage, the amount of asphalt further increases. and improves lubrication between particles. Unlike the first stage in which no complete connection exists between the aggregate particles and asphalt, active movement of the aggregate particles is restricted. The amount of residual air, on the other hand, becomes smaller and the mixture does denser as compared with those in the second stage, with the maximum D_m existing.

The value of S_t at the maximum D_m decreases in comparison with that in the second stage, and the maximum S_t is generally obtained at the point where the amount of asphalt is lower than that at the maximum D_m point.

In the fourth stage, the amount of asphalt further increases as compared with that in the preceding stage, and the amount of residual air becomes minimum ; accordingly, the cohesive force between the aggregate particles decreases, S_t becomes smaller, F_l value increases, D_m decreases, and V_v showing a minimum stays at the same value or tends to increases slightly.

SUMMARY

In the Marshall tests, there exist the amounts of asphalt at maximum S_t and maximum D_m and that at minimum V_{ma}. Generally, with increasing F/A and G/S, the maximum S_t and maxiumu D_m increase, the minimum V_{ma} decreases, and the amounts of asphalt at each point decrease.

The F_1 value at the maximum S_t and that of V_v at the maximum D_m decrease, but this tending does not hold if they exceed the critical regions.

The values of V_{mg} and V_{fm} how the same tendency as those of V_{ma} and V_{fa}, but reach the critical values soon, so clear tendencies are hardly obtainable. Therfore, comparison is difficult without preparing specimens with accurate densities.

CONCLUDING REMARKS

The results of experiment performed this time lead to the following conclusions: The results of the Saybolt Furol viscosity tests for binder by using various F/A and fine filler indicate that the viscosity of very fine filler is high, and becomes higher with increasing F/A. This may be because filler bitumen containing very fine particles makes the contact area with aggregates greater, and because film thickness is thin in addition to hard viscosity.

The results of the Marshall tests show that the influence of very fine filler in asmor becomes greater because filler increases with the increasing binder contents.

At a mixing temperature of 180°C, bitumer degraded, hardened and greatly affected the strength of the asphalt mixes.In ascon containing the small amount of asphalt in particular, the difference in stability is clearly observed, but little influence is observed if very fine filler is used.

It was found that the use of very fine particle size filler made viscosity higher, but that it inhibited the degradation of bituminous materials.

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