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Experimental Research on Ultra Thin Friction Course Interlayer Bonding Strength

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Abstract: An ultra thin friction course (UTFC) is a good performance preventive maintenance technology. Its many properties that improve performance include improved skid resistance, quieter driving ride, harder wearing surface, and effective waterproofing. The study reported in this paper investigates the relationships between the interlayer shear strength and the interlayer bonder properties, amounts of sprayed emulsion bonding agent, and aggregate gradation of the UTFC-10 bituminous mixture through direct shear testing using an interlayer shearing device. The results indicate that the styrene-butadiene-styrene tri-block polymer (SBS)-modified asphalt emulsion studied is a desirable interlayer binder for use with UTFC treatment. The desirable SBS content of the emulsion should be more than 2.5% by weight, the amount of sprayed emulsion should be about 0.8 to 1.2*L* per square meter, and the percent air voids in UTFC bituminous mixture should be limited to 8 to 10%.

Key words*: Direct shear testing; Interlayer shear strength; Modified asphalt emulsion; Ultra thin friction.*

Introduction

An ultra thin friction course (UTFC), as shown in Fig. 1 [1], is a relatively new preventive maintenance treatment. It consists of a 10- to 20-*mm* thick gap-graded, polymer-modified bituminous mixture layer bonded to the existing pavement surface with a tack coat consisting of a polymer-modified asphalts emulsion. The treatment is especially suitable for repair of pavements that are losing their surface quality, partially or entirely, from distresses that include longitudinal, transverse and block cracking, raveling and weathering, friction loss, roughness, and bleeding. Some other functional features of the road are also improved such as improved skid resistance, quieter driving, better surface wear resistance, and effective waterproofing [2, 3].

The construction of an UTFC is carried out using a self-priming paver as shown in Fig. 2 [1]. The spraying of emulsion tack coat and the placing of the paving mixture are completed simultaneously; therefore, the curing time is quick and construction quality is more easily controlled. Because of the increased attention being given to the enlarging preventive maintenance market, more interest is being focused on the treatment [4].

There are many factors that directly affect the construction and application; however, the shear strength of the interlayer is a key factor. In the work described in this paper, a specimen is first prepared using a mixture containing an AC-16 asphalt and an aggregate gradation typical of an existing pavement. A styrene-butadiene-styrene tri-block polymer (SBS)-modified asphalt emulsion is brushed on the surface of the mixture as a tack coat, and finally, the graduation UTFC-10 mixture is placed upon it to form a compound specimen. The relationships between shear strength of the specimen and bonding properties, the amount of emulsion applied, and the gradations of the bituminous mixture were investigated by direct shear testing.

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Experimental Program

Influencing Factors

Polymer-Modified Asphalt Emulsion

To be used as a UTFC interlayer bonding agent, the polymer-modified asphalt emulsion should meet the following requirements [5]: (a) a quick-breaking emulsified asphalt with low viscosity, (b) a solids content greater than 62% by weight, and (c) good adhesive bonding after curing.

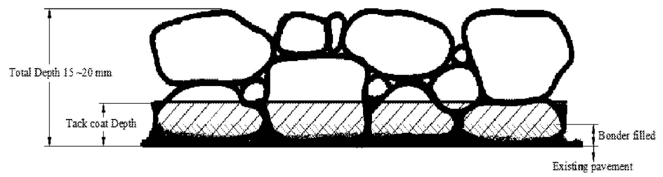

Fig. 1. Structure of the Ultra Thin Friction Course.

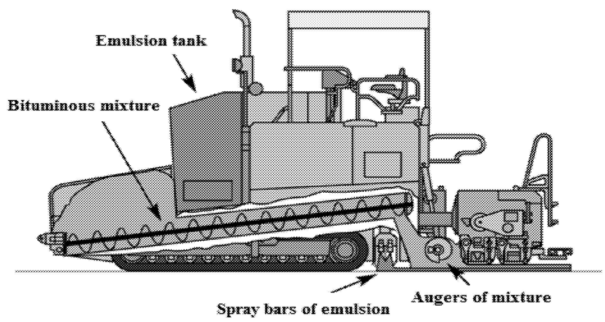

Fig. 2. Self-Priming Paver.

Table 1. Emulsion Evaporation Residue Properties.

	SBS Content of Emulsion, Weight %			
	1	2	3	4
Solids Content, %	62.8	62.1	62.5	63.4
Penetration at 25 ℃ (100*g*, 5 s), *mm*	96.1	89.0	78.0	67.0
R&B Softening Point (5 ℃ /min), ℃	50.6	53.5	58.4	62.8
Ductility at ℃ (5 *cm*/min) , *cm*	12.5	22.5	38.8	44.8
Elastic Recovery at 25 ℃, %	24.6	58.5	70.5	85.6

Table 2. Gradation of UTFC-10.

Volume of Air Voids, %	Aggregate Passing, %			
	8	10	12	14
Sieve Size, *mm*				
13.2	100	100	100	100
9.5	98.0	94.8	91.2	88.4
4.75	35.8	32.8	30.4	27.8
2.36	29.1	26.6	24.1	22.7
1.18	26.2	23.4	21.7	18.1
0.6	18.4	17.0	16.4	14.0
0.3	13.5	11.3	10.3	9.3
0.15	10.7	9.6	8.6	7.9
0.075	6.8	5.9	5.5	4.9

Fig. 3. Shear Device for Direct Shear Testing.

A SBS-modified asphalt was emulsified with a lab-emulsifier that met the national specification (JTG F40-2004 [6]) for solids content and emulsion breaking speed. The properties of the evaporation residue are presented in Table 1.

Table 1 shows that when the amount of SBS emulsion was increased, the softening point, ductility, and elastic recovery were increased and the penetration decreased. It is believed that the adhesion of the emulsion residue to the coarse mineral aggregate was improved by SBS because the viscoelastic properties of the bitumen (e.g., penetration and softening point) increased. Furthermore, the toughness properties (e.g., ductility and elastic recovery) were improved because the SBS has a special ability to improve the bonding strength. In this paper, the shear strength using different amounts of SBS was studied.

Bituminous Mixture Gradation

The design of a UTFC is similar to that of a gap-grading structure, which can improve the inter-bonding ability because of the volume of air voids in the mixture. For this reason, the percent air voids in mixture is a key factor to be considered in the design of the experiments. The gradations of the UTFC-10 mixtures with different percent air voids are shown in Table 2.

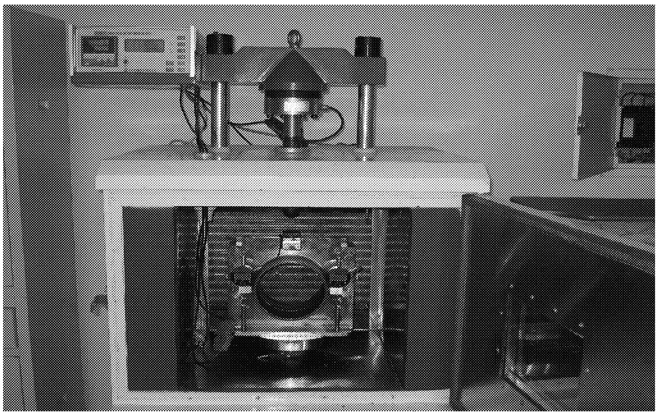

Fig. 4. Loading Equipment Equipped with Shear Device.

Experimental Design

The research in this study included two tasks. Task A investigated the relationship between shear strength and the content of SBS in the emulsion, while the percent air voids in UTFC-10 mixture was fixed at 9.8%. In Task B, the relationship between the shear strength and the amount of emulsion used and air voids in mixture were studied, while the content of SBS in the emulsion was held constant at 3% by weight.

Loading Experiment

Shear Testing Device

The equipment used for the shear testing consisted of a frame, a sliding panel, and bracket as shown in Fig. 3. The splint fixed on the splint is used for bracing the specimen; the sliding panel fits in the groove-like part of bracket, and the panel can be slid up and down. Before testing, the shearer is adjusted and the specimen is put into its circular sleeve, and then the joint line of specimen is aligned with to gap-line of the splint between the sliding panels. During the testing, the two parts of the specimen are slid relative to each other along the joint line until the tack coat is broken down.

Loading Equipment

An ordinary material testing system (MTS) with a temperature-controlled box was utilized for loading, and the shear device was placed on the box as shown in Fig. 4. The equipment was used with a data acquisition system and loading rate adjustment. Using this system, the stress-stain curve could be obtained and its peak value recorded.

Environmental Temperature

In actual practice, the interlayer is easily slipped and broken at high temperatures (JTJ 052-2000 [7]), and 60 ℃ is the general testing

Table 3. Interlayer Shear Strength of Difference Loading Rate.

Temperature, ℃	Interlayer Shear Strength, *MPa*	
	25	60
Loading Rate, *mm*/min		
5	0.665	0.139
10	0.845	0.375
20	1.104	0.478
35	1.029	0.567
50	1.029	0.572

Table 4. Specimen Properties and Their Required Values.

Specimen Property		Requirement
UTFC-10 Bituminous Mixture		
Asphalt Binder	SBS Modified	Performance Grade (PG) 76 ~ 22; Soften Point Greater Than 70 ℃; Ductility at 5 ℃ Greater Than 40*cm*
Coarse Aggregate	Limestone	Complying with Specification (JTG E42-2005 [8])
Mixture Volume Properties		
Volume of Air Voids, %		8 ~ 14
Voids in Mineral Aggregate, %		> 18
Voids Filled with Asphalt, %		45 ~ 55
AC-16 Bituminous Mixture		
Asphalt Binder	SBS Modified	Performance Grade (PG) 70-22
Coarse Aggregate	Basalt	Complying with Specification (JTG E42-2005 [8])
Mixture Volume Properties		
Volume of Air Voids, %		3 ~ 5
Voids in Mineral Aggregate, %		12.5 ~ 14.5
Voids Filled with Asphalt, %		65 ~ 75

temperature for the bituminous equipment [7]. Therefore it was decided to use this temperature as the environmental temperature for Task A. For Task B, 25 ℃ was chosen. Before testing, the temperature of the environmental chamber was leveled off at the specific temperature, and the specimen was then placed in the box for four hours to reach equilibrium.

Loading Rate

It is important to determine the most suitable loading rate for direct shear testing. For the work reported in this paper, the loading rates selected were 5, 10, 20, 35, and 50*mm*/min, and measurements were made at two temperatures. Results are shown in Table 3.

According to the data of Table 3, it can easily be seen that when the loading rate is greater, the interlayer shear strength is greater; when the loading rate is 50*mm*/min, the shear strength is higher than for the other three rates. It is easier to distinguish the different performances of specimens when the value is higher because of the lower relative error ratio. Thus, the loading rate selected for use was 50*mm*/min.

Specimen Preparation

Table 5. Results of Task A.

Emulsion Sprayed Amount, *L/m²*	Interlayer Shear Strength, *MPa*			
	0.6	0.8	1	1.2
SBS Content by Weight, %				
0	0.076	0.086	0.066	0.059
1	0.092	0.116	0.139	0.127
2	0.103	0.139	0.171	0.156
3	0.152	0.177	0.228	0.309
4	0.285	0.309	0.425	0.378

Table 6. Results of Task B.

	Interlayer Shear Strength, *MPa*			
SBS Content by Weight, %	3			
Voids Percentage of UTFC-10, %	8	10	12	14
Emulsion Sprayed Amount, *L/m²*				
0.6	1.552	1.505	1.432	1.358
0.8	1.696	1.606	1.559	1.474
1	1.689	1.766	1.684	1.585
1.2	1.642	1.752	1.789	1.676
1.4	1.542	1.688	1.771	1.66

Table 7. Results of Regression.

Variable	Parameter	Model A(x_1, x_2)	Model B(x_2, x_3)
X_1^3	a_1	- 0.034	0.000
X_2^3	a_2	0.005	- 0.550
$X_1^2 X_2$	a_3	- 0.018	- 0.021
$X_1 X_2^2$	a_4	- 0.013	0.084
$X_1 X_2$	a_5	0.152	0.367
X_1	a_6	- 0.080	- 0.149
X_2	a_7	0.043	- 1.260
Constant	C	0.063	0.242
Correlation	R^2	0.967	0.975

Specimen Composition

The composite specimen consisted of three parts: the 50*mm* top layer of UTFC-10, which is bonded to the lower 50*mm* layer consisting of an AC-16 mixture using a SBS-modified asphalt emulsion. The diameter of the specimen is 150*mm*. Material properties and specifications are showed in Table 4.

Preparation Method

The composite specimen was prepared using a gyratory shearing compactor (GSC), and the process was as follows: (1) prepare an AC-16 mixture specimen and then keep it in the steel mold; (2) prepare a UTFC-10 mixture and place it in an oven at 165℃ until used; and (3) brush the emulsion on the surface of cooled specimen AC-16 in the mold, and quickly place the UTFC-10 mixture into the mold onto the tack coat before the emulsion breaks. Finally, compact the composite specimen to the required thickness.

Results and Discussion

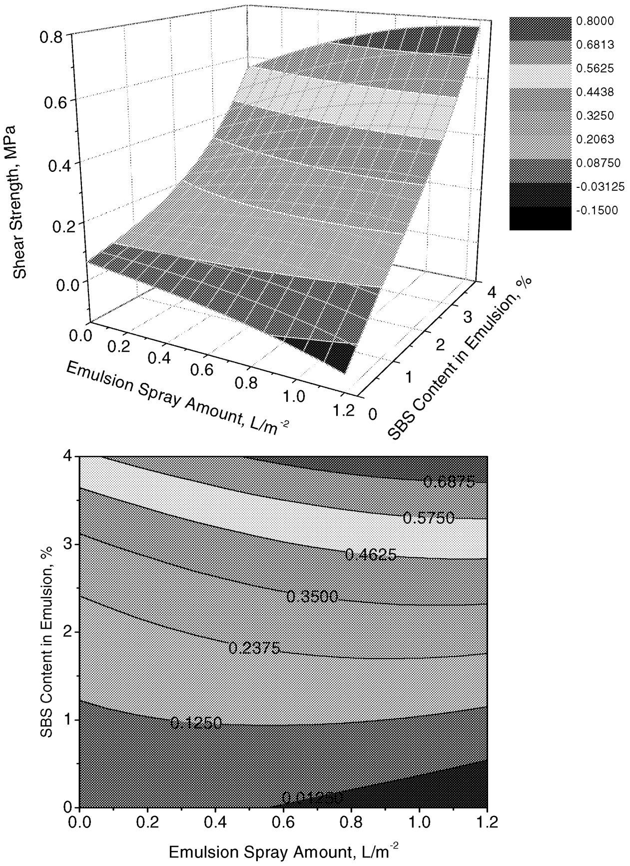

Fig. 5. Response Surface of Model A.

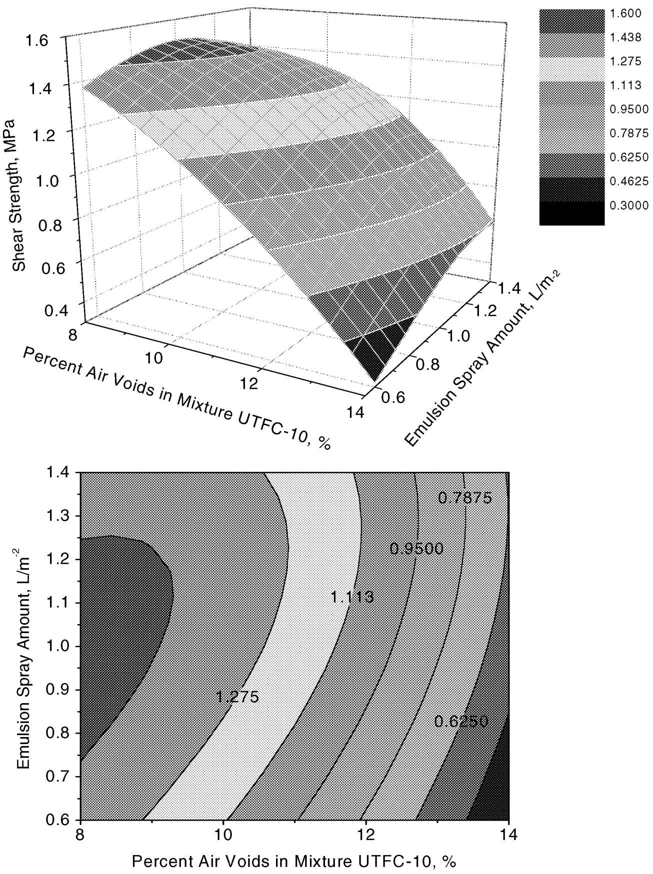

Fig. 6. Response Surface of Model B.

Analysis of Results

The results of Task A and B are shown in Table 5 and 6. Using cubic polynomial model as Eq. (1) to analyze the results of Task A and B, the higher correlation can be received. Where, in Eq. (1), Y is the interlayer strength, X_1 and X_2 are major two factors affect on interlayer strength accordingly.

$$Y = a_1X_1^3 + a_2X_2^3 + a_3X_1^2X_2 + a_4X_1X_2^2 + a_5X_1X_2 + a_6X_1 + a_7X_2 + C \quad (1)$$

With Eq. (1), on regression for results of Task A, make x_1 as X_1 and x_2 as X_2, the regressing parameters of Model A is shown as column "Model A(x_1, x_2) in Table 7. Where, x_1 is SBS content of the emulsion and x_2 is the amount of emulsion sprayed.

Similarly, on regression for results of Task B, make x_2 as X_1 and x_3 as X_2, the Model B can be received as shown in Table 7. Where, x_2 is same as above and x_3 is the percent of air voids in the UTFC-10 mixture.

Because of high correlation, it is 0.967 and 0.975 for Model A and B, respectively. It is reasonably easy to describe the relationship between x_1, x_2, and Y as well as the relationship between x_2, x_3, and Y. According to results of regression in Table 7, the curves of Model A and B can be plotted for discussion of the results of the investigation.

Discussion

SBS Content and Amount of Emulsion Sprayed Effect on the Interlayer Shear Strength

The curve shown for Model A is a dimensional response surface limited by zone ($0.0 < x_1 < 1.2$, $0 < x_2 < 4$), received isoline to project the surface on the X-Y plane, as show in Fig. 5. With the isoline, each point on a same curve is equal; the representative value has been marked on the curve, and the change in the trend of the value of the independent variable can be observed visually. In the figure, it can be observed that the value of the shear strength increases in the direction from the bottom, left-hand corner in the limited zone to the top, right-hand corner, while reaching the optimal value in the zone ($0.5 < x_1 < 1.2$, $3.8 < x_2 < 4.0$). As explained, the higher the SBS content, the greater the value of the shear strength. According to the discussion about the data of Table 1, it is considered that the SBS-modified asphalt emulsion is suitable for use as the UTFC interlayer bonder and the SBS functions increase and improve the adhesive bonding at the interlayer. Thus, the SBS content of emulsion should be increased to reinforce the shear strength.

Percent Air Void and Amount of Emulsion Sprayed Effect on the Interlayer Shear Strength

As show in Fig. 6, the curve of Mode B is a dimensional response surface similar to that of Model A, but is much different regarding changes in the trends shown in Model A. According to the isoline of the curve, the shear strength is increased from nearside to offside in limited zone ($0.0 < x_2 < 1.2$, $8 < x_3 < 14$), and the optimal value was reached within the scope ($0.74 < x_2 < 1.25$, $8 < x_3 < 9$). The change trend of the curve indicates that the interlayer bonding strength is influenced by the gradation of UTFC-10 mixture. The trend of the curve change indicate that interlayer bonding strength is influenced by the gradation of UTFC-10 mixture: Given a percent air voids level, a suitable scope of emulsion spray amount can be in existence to reach higher interlayer bonding strength; beyond the scope, interlayer bonding strength can be decreased.

Suitable Processing Condition Decision

According to the analysis about SBS content and amount of emulsion sprayed effect on the interlayer shear strength, increasing the SBS content could improve the UTFC interlayer bonding shear strength. As the isoline in Fig. 5 illustrated, the curves of within the scope of 2 to 4% is denser than the scope below 2.5% that limited in spray amount scope of 0.8 to $1.2L/m^2$. As a result, the SBS content should not be less than 2% for an interlayer bonder.

Furthermore, on the basis of the discussion about the percent air voids and amount of sprayed emulsion effect on the interlayer shear strength, the desirable percent air voids should be controlled between 8 to 10% when the amount of SBS is limited to 2 to 4%, and the amount of emulsion spray is between 0.8 to $1.2L/m^2$. As such, desirable interlayer shear strength should be obtained.

Conclusions

The shear testing equipment used is applicable for investigating the direct shear strength of the interlayer bonding performance based on the data obtained. It seems obvious that the equipment is reliable, based on the regularity shown by the results of the testing.

The following is concluded regarding the relationships between the UTFC interlayer shear strength and the interlayer bonder properties. SBS-modified asphalt emulsion is a desirable bonder to choose for UTFC. The SBS content is an important factor influencing the bonding in the UTFC treatment because it improves the adhesive bonding at the interlayer, and the SBS content should not be less than 2.5%. The gradation of UTFC mixture and the amount of emulsion spray on the UTFC interlayer work together to improve shear strength. For a well-designed UTFC layer, the void content of the mixture should be kept between 8 and 10% and the amount of emulsion spray between 0.8 to $1.2L/m^2$.

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