stretching vibration zone, which is caused by the conjugated C=C and C=O stretching vibrations. This area meets the requirements of aromatics. The monocyclic aromatic hydrocarbons are in the vicinity of $1600cm^{-1}$ and $1500m^{-1}$. Two absorption peaks can be used to determine the presence of aromatics. The absorption of the wave number of 650.39 cm^{-1} is caused by the C-H out-of-plane rocking vibration on the benzene ring. The above analysis shows that the emulsified asphalt is mainly composed of a saturated hydrocarbon, an aromatic compound and a hetero atom derivative, and a partial absorption peak may be constituted by an infrared test. Due to the absorption peak of the emulsified asphalt, the comprehensive component analysis of the emulsified asphalt cannot rely solely on infrared. This paper mainly compared with the modified fiber emulsified asphalt.

Tab. 1 Infrared samples of fiber of emulsified asphalt with different modification methods

Fiber Variety	Basalt Fiber						Glass Fiber					
Treatment Solution	NaOH		H_2SO_4		KH550		NaOH		H_2SO_4		KH550	
Concentration(mol/L)	1	2	1	2	0	1	1	2	1	2	0	1
Sample	A-J1	A-J2	A-S1	A-S2	A-O0	A-O1	B-J1	B-J2	B-S1	B-S2	B-O0	B-O1

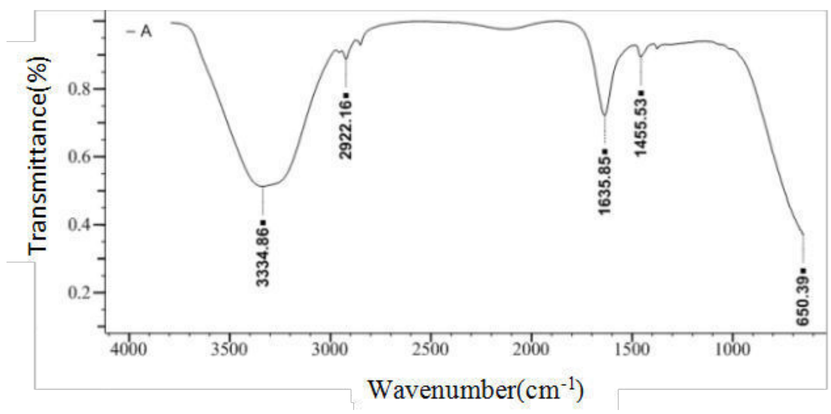


Fig. 1 FTIR spectra of original emulsified asphalt

Effects of different concentrations of acid-base on interface of modified fiber emulsified asphalt

The infrared spectra of emulsified asphalt adsorbed by modified basalt fiber and glass fiber are shown in Fig. 2 and Fig. 3. Fig. 2 shows the full band infrared spectrum of original sample and four modified basalt fiber emulsified asphalt. Fig. 3 shows the full band infrared spectrum of the original sample and 4 kinds of modified glass fiber emulsified asphalt. The modified infrared spectra showed no new characteristic peaks, indicating that the functional groups contained in the compositions did not change. And the interfacial physical adsorption of etched basalt fiber and glass fiber with emulsified asphalt occurs mainly. But the characteristic wave number of each sample has a slight change, as shown in Table 2. The wave number in the infrared image characterizes the vibration frequency, and wave displacement is the displacement of the vibration frequency. The factors affecting frequency displacement can be divided into external and internal factors. External factors include physical state, solvent and particle size. In this test, the emulsified asphalt was in the liquid state and the solvent used potassium bromide with the same particle size, so the interference of external factors was excluded, indicating that the displacement was mainly caused by internal factors.

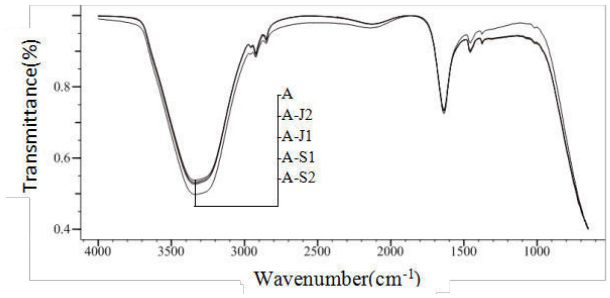


Fig. 2 FTIR spectra of original and 4 kinds of modified basalt fiber of emulsified asphalt

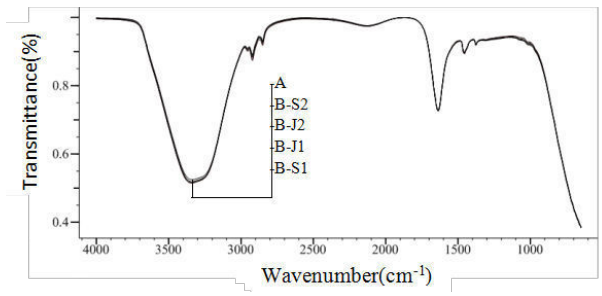


Fig. 3 FTIR spectra of original and 4 kinds of modified glass fiber of emulsified asphalt

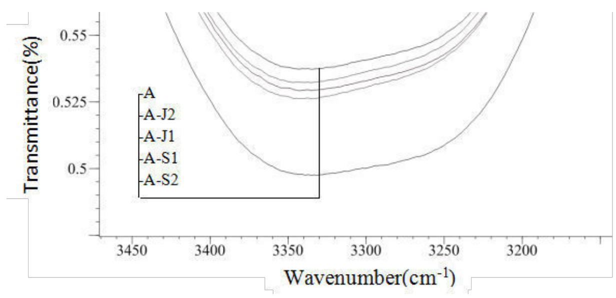


Fig. 4 FTIR spectra of original and 4 kinds of modified basalt fiber of emulsified asphalt in the wave number of 3200-3450cm^{-1}

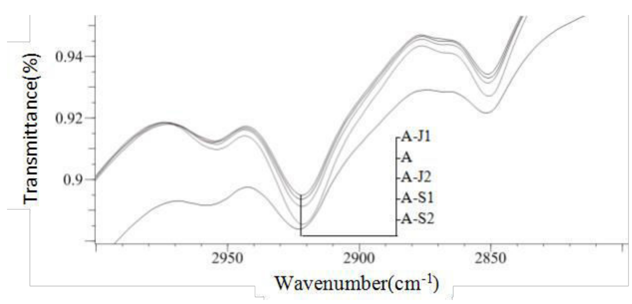


Fig. 5 FTIR spectra of original and 4 kinds of modified basalt fiber of emulsified asphalt in the wave number of 2850-2950cm^{-1}

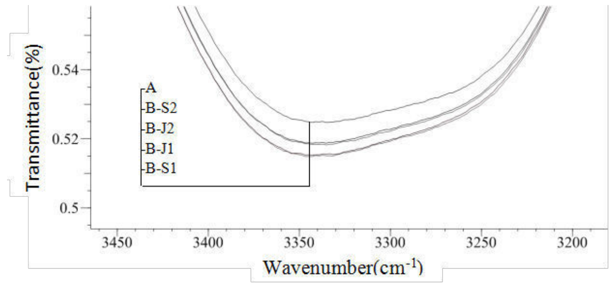


Fig. 6 FTIR spectra of original and 4 kinds of modified glass fiber of emulsified asphalt in the wave number of 3200-3450cm^{-1}

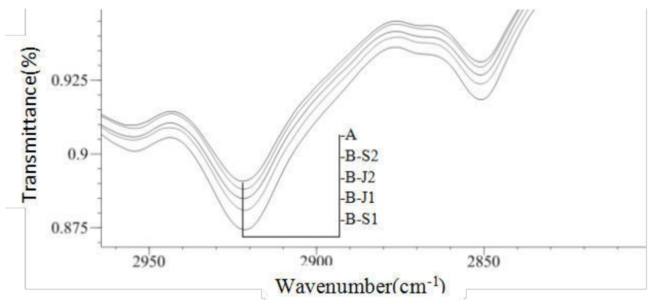


Fig. 7 FTIR spectra of original and 4 kinds of modified glass fiber of emulsified asphalt in the wave number of 2850-2950cm^{-1}

Tab. 2 The peak wave number of infrared spectra of original and modified basalt and glass fiber of emulsified asphalt

classification	sample								
	A	A-J1	A-J2	A-S1	A-S2	B-J1	B-J2	B-S1	B-S2
Wave number	3334.86	3343.05	3335.34	3334.86	3331.48	3345.95	3343.05	3343.05	3335.34
	2922.16	2921.68	2921.68	2921.68		2921.19	2921.68	2921.19	2921.68
	1635.85	1636.33	1635.85	1635.85	1635.85	1635.85	1636.33	1635.85	1635.85
	650.39	652.31	652.80	652.80	650.39	650.39	650.39	650.39	650.39

At the same time, according to Fig. 4, 5, 6 and 7, the characteristic peaks also had a slight increase or decrease, indicating that the corresponding functional group content of the characteristic peaks had increased or decreased. Fig. 4 and 5 respectively show the infrared spectra of original samples and 4 kinds of modified basalt fiber emulsified asphalt in 3200-3450 cm^{-1} wave region and 2850-2950 cm^{-1} wave region. Fig. 6 and 7 respectively show the infrared spectra of original and 4 kinds of modified glass fiber emulsified asphalt in 3200-3450 cm^{-1} wave region and 2850-2950 cm^{-1} wave region.

As shown in Fig 4 and 5 , the characteristic peaks at 3334.86 cm^{-1} representing the O-H stretching vibration in A-J1, A-J2, A-S1 and A-S2 all increase compared with A, indicating that the content of -OH increases. However, in A-J1 and A-S2, the characteristic peaks at 2922.16cm^{-}

[1] representing the saturated C-H stretching vibration weakened, indicating that the saturation fraction decreased, while in A-J2 and A-S1, the characteristic peaks increased. Because the acid-base treated basalt fiber immersed in emulsified asphalt, the emulsified asphalt adsorbed -OH in the fiber, while the fiber adsorbed saturated fragrance in the emulsified asphalt. The results showed that the modified basalt fiber adsorbed the emulsified asphalt, and the content of -OH in the 1 mol/L alkali modified basalt fiber increased more obviously than that in the 2 mol/L, but the content of saturated fragrance decreased, while the result of acid modified basalt fiber was opposite to that of alkali.

Fig 6 - 7 show that the characteristic peaks at 3334.86 cm^{-1} representing O-H stretching vibration and 2922.16 cm^{-1} representing saturated C-H stretching vibration all increase in B-S1, B-S2, B-J1 and B-J2 as compared with A, indicating that the content of-OH and saturated fragrance increase in different modification methods. The reason is that the glass fiber with different concentration of acid-base modification is added to the emulsified asphalt, and the material exchange occurs between the two, and the -OH in the fiber and saturated fragrance enter into the emulsified asphalt during the immersion process, so the modified fiber and the emulsified asphalt are adsorbed. The results show that the modified glass fiber is helpful to improve the combination with emulsified asphalt, and as we can see from the diagram, the characteristic peaks of B-S1 are obviously different from those of B-J1, B-J2 and B-S2, which indicates that the adsorption effect of 1 mol/L acid modified glass fiber combined with emulsified asphalt is more obvious.

Effect of coupling agent on the interface of modified fiber emulsified asphalt

Fig. 8 is illustrated that the infrared spectrum of unmodified and coupling agent modified glass fiber and basalt fiber emulsified asphalt. The active characteristic peak 3441.51cm^{-1} is caused by free O-H stretching vibration. 2923.5cm^{-1} and 2853.38cm^{-1} are in the range of 2800-3000cm^{-1}. Its characteristic is the saturated c-h stretching vibration of alkanes, which is the asymmetric stretching vibration outside the methyl(CH_2) surface. 1632.75cm^{-1}, 1455.31cm^{-1} are caused by the skeleton vibration of the aromatic ring, 1376.6cm^{-1} is caused by the bending vibration of CH_2, and the active peaks near 650-900cm^{-1} are all caused by the bending vibration of C-H on the aromatic ring. The analysis shows that the components of emulsified asphalt added by unmodified and coupling agent modified fibers are the same as the original emulsified asphalt.

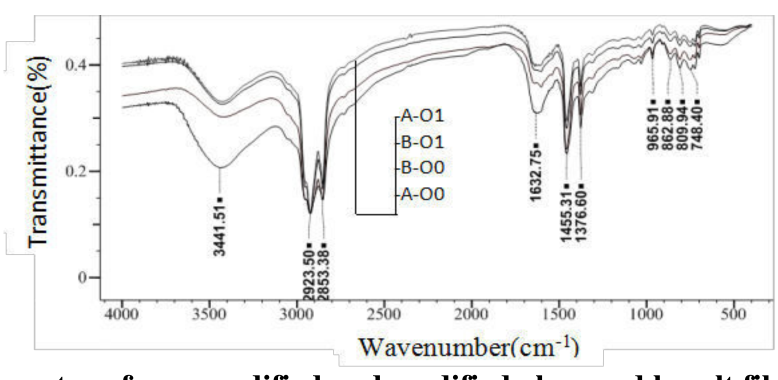
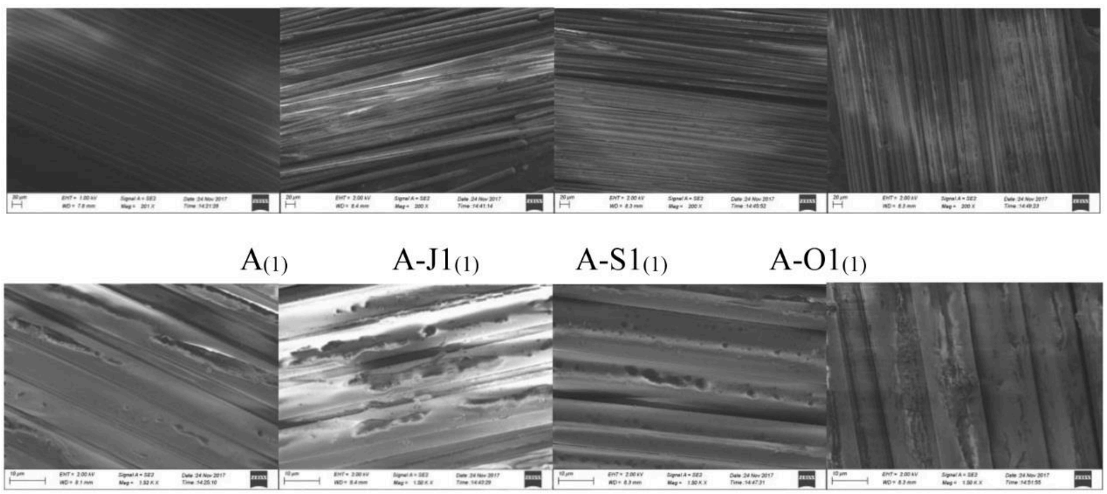


Fig. 8 Infrared spectra of non-modified and modified glass and basalt fiber of emulsified asphalt

Compared with A-O1 and A-O0, B-O1 and B-O0 increase the characteristic peaks of 2923.5

cm^{-1} and 2853.38 cm^{-1}, which represent the stretching vibration of saturated C-H, indicating that the content of saturated components increases and the active peaks of 1632.75 cm^{-1} and 650-900 cm^{-1} decrease, indicating that the content of aromatic components decreases.Since the coupling agent-modified basalt fiber and glass fiber are added to the emulsified asphalt, a certain amount of silane on the surface of the fiber acts as a bridge, and the fiber and the emulsified asphalt are combined, and material exchange occurs between the two, resulting in adsorption of the emulsified asphalt. The saturated fraction in the fiber, while the fiber adsorbs the aromatic component in the emulsified asphalt. Above analysis, fiber coupling agent is added in the emulsion of modified bitumen, compared to untreated fiber, functional group content portion is increased, the coupling agent described played a good bridging effect, the adsorption effect of both have a certain Enhanced.



A$_{(1)}$ A-J1$_{(1)}$ A-S1$_{(1)}$ A-O1$_{(1)}$

A$_{(2)}$ A-J1$_{(2)}$ A-S1$_{(2)}$ A-O1$_{(2)}$

Fig. 9 SEM images of original and modified basalt fiber

Analysis of Fiber by scanning electron microscopy

Figure 9 is an SEM image of the original basalt fiber and modified basalt fiber.It can be seen that the low-magnification samples are distributed around 20μm, the surface of A$_{(1)}$ is smooth and cylindrical, and the arrangement is regular. The surfaces of A-J1$_{(1)}$, A-S1$_{(1)}$ and A-O1$_{(1)}$ are also arranged regularly. The shape is unchanged and the fineness is relatively uniform, but traces of solution etching are clearly observed.Sample A-J1$_{(1)}$ Part of the mono filament fiber was broken. The high-magnification sample is distributed at about 10μm, and the surface of the sample A$_{(2)}$ has pits and cracks, and the size of the pit is about several hundred nm.The cause of the defect may be that the fiber is formed during high temperature preparation or is related to the aggregation of the surface modifier after fiber preparation.The surface of the sample A-J1$_{(2)}$ peeled off, resulting in a new smooth surface with a small amount of scaly material. The spelling was caused by the surface of the fiber reacting with the alkaline medium to form a corrosion layer on the surface. And the corrosion layer will produce corresponding cracks. The alkali solution enters the new surface under the corrosion layer through the crack, and the corrosion layer peels off due to the stress between the corrosion layer and the new surface.A large number of large and small pits were generated on the surface of sample A-S1$_{(2)}$, and the distribution was uniform. Due to the acid etching, the partially polymerized Si-O-Si bond was broken under H+

to form Si-OH bond. It is affected and gradually declines. Although the surface is loose, its structure is still glassy. The surface of the sample A-O1$_{(2)}$ had cracks in the direction of the fiber accompanied by a small amount of convex and scaly substances. In the coupling agent modification, the surface of the fiber is grafted with a specific functional group in the coupling agent molecule, and the fiber is bonded to the substrate by "bridge" action. The above analysis can be obtained, the material is relatively smooth and microscopically, and has a certain roughness on the microscopic surface, which is beneficial to the interface enhancement of the composite material to some extent, wherein the alkali etching causes the overall structure of the fiber to be destroyed, and the coupling agent etching structure Complete, but uneven etching, acid etching to maintain a complete structure and uniform etching, so the best modification effect is 1mol / L acid etching.

CONCLUSION

The infrared image of modified fiber emulsified asphalt is similar to the shape of the original emulsified asphalt. The main active characteristic peaks is the same about the number and positions, meanwhile no new characteristic peaks are generated. The main phenomenon is physical adsorption. The difference is that the characteristic peaks and wave numbers occurred slightly increase and decrease.

When adding acid-base modified glass fiber to emulsified asphalt, it found that the enhancement of the B-S1characteristic peak is obvious compared with B-J1, B-J2 and B-S2, indicating 1mol/L acid-modified glass fiber and emulsified The adsorption effect is best after asphalt is combined. The addition of acid-base modified basalt fiber to emulsified asphalt showed that the increase of -OH content of 1mol/L base was more obvious than 2mol/L, but the content of saturated fraction decreased, while the acid modification result was opposite to that of alkali. Therefore, it is indicated that the acid-base modified fiber contributes to the improvement of adhesion to the emulsified asphalt.

The glass fiber and basalt fiber treated by the coupling agent were added into the emulsified asphalt. Compared with the untreated fiber, the content of some functional groups increased, indicating that the coupling agent played a good bridging effect, and the adsorption effect of the two. There is a certain enhancement.

The original and modified basalt fiber is smooth and microscopically smooth, and has a certain roughness on the microscopic surface, which is beneficial to the interface reinforcement of the composite material to some extent, wherein the alkali etching causes the overall structure of the fiber to be destroyed, and the coupling agent The etching structure is complete, but the etching is not uniform, the acid etching keeps the structure intact and the etching is uniform, so the modification effect is best etched by 1mol/L acid solution.

REFERENCES

B.H. Li and Y.J. Zhu. (2006).“Investigation and Analysis of Highway Asphalt Concrete Pavement Diseases.” *J. Highway*, 10(2):206-212.

Nirmal Dhakal, Mostafa Elseifi and Z.J. Zhang.(2016).“ Mitigation Strategies for Reflection Cracking in Rehabilitated Pavements-A Synthesis.”*J. International Journal of pavement research and Technology,* 9: 228-239.

Young S. Doh, Sung H. Baek and Kwang w. Kim.(2008). “Estimation of relative performance of reinforced overlaid asphalt concrete reflection cracking due to bending more fracture.”*J.Construction and Building Materials,* 23:1803-1807

B. Yang.(2013).*Surface and Interface of Polymer Materials.* China Standard Press, Beijing,
Y.Y. Liu , T.Q. Ling and K. Jiang.(2012). “Study on Crack Resistance of Fiber Reinforced Emulsified Asphalt based on Fracture Energy.” *J. Highway*, (8): 201-207
P. Chen and H. Chen. (2010).*Interface and Fiber Surface Modification of Advanced Polymer Matrix Composites.* Science Press, Beijing
Z.S. Ge, H. Wang and Q.S. Zhang.(2015). “Glass Fiber Reinforced Asphalt Membrane for Interlayer Bonding between Asphalt Overlay and Concrete Pavement.” *J. Construction and Building Materials,* 101:918-925
L. Liu , C.H. Liu and Y. Xiang .(2017).“The Mechanism and Pavement Performance of Silane Coupling Agent Modified Basalt Fiber.” *J. Journal of Building Materials,* 20 (1): 150-155.
Wu G M, Hung C H and You J H .(2004). “Surface Modification of Reinforcement Fibers for Composites by Acid Treatments.” *J. Journal Polymer Research,* 11(1):31-36
L. Zhang.(2011).Effect of Basalt Fiber Surface Treatment on Properties of Composites. Beijing Forestry University, Beijing
Z.J. Zhang, L. Hua, H.X. Li and L.R. Cui.(2013).“ Application of Silane Coupling Agent in Glass Fiber Reinforced Composites.” *J. Glass Fiber,* (3): 1-22.
P. Sun , T. Jin and S. Tian.(2016). “Study on Silane Coupling Agent Modified Glass Fiber Reinforced PA6 .”*J. New Chemical Materials,* 44 (1): 205-207

Exploratory Analysis of Long-Term Performance of Pavement Using Reclaimed Asphalt Pavement

Zijun Mei[1]

[1]Shanghai Municipal Engineering Design Institute (Group) Co., Ltd., Gemini A601, Qingfen Rd. North, Yubei District, Chongqing, China. E-mail: 522316177@qq.com

ABSTRACT

As the development of automatic pavement performance data collection equipment, the amount of data faced by pavement managerial agencies becomes intractable. Due to the massive amount of data available at the pavement management system, it is difficult to determine which data element is the most important. This paper aimed to addressing this issue through an exploratory analysis of the data from the long-term pavement performance (LTPP) program. The data primarily collected from the specific pavement study 5 (SPS-5) were analyzed in the study. The results in the study showed the cracking especially the alligator and wheel path longitudinal cracking significantly impacted the deterioration of the pavements' long-term performance. The rutting was more crucial to the riding quality of the asphalt pavement than the cracks. The sections containing up to 30% RAP achieved similar performance in terms of IRI, wheel path longitudinal cracking, and transverse cracking. Compared with section using virgin HMA only, sections containing RAP showed less rutting.

Keywords: LTPP; Data; Asphalt Pavement; Management

INTRODUCTION

The long-term pavement performance program has been a huge incentive for numerous research activities (Hong et al. 2010; Gong et al. 2015; Dong and Huang 2015; Ahmed et al. 2013). To obtain better understanding of long-term pavement performance, the Federal Highway Administration (FHWA) initiated the long-term pavement performance program (LTPP) to study how pavement performance is affected by various design features, environmental effects, traffic loads, materials, construction quality, and maintenance practices (Hall et al. 2002; West et al. 2011; Gong et al. 2015). Maintenance is defined as preservation of pavement condition, safety, and ride quality (Hall et al. 2002; Haider and Dwaikat 2011; Wang et al. 2012). Rehabilitation is defined as a structural or functional enhancement that produces substantial extensions in service life, by substantially improving pavement condition and ride quality (Hall et al. 2002). Many studies have addressed the performance of pavement using hot mix asphalt containing no reclaimed asphalt pavement (RAP) materials, while relatively few have dealt with those utilized RAP due to absent of adequate data. Von Quintus et al. (2006) investigated different rehabilitation strategies on the long-term performance of pavement overlays with and without reclaimed asphalt pavement (RAP). With the rapid advancement of pavement performance data collection equipment, pavement engineers are overwhelmed with massive data collected by autonomous equipment.

Pavement management agencies have been striving to optimize the resources for keeping the highway system in good riding quality. Numerous studies have been conducted to optimize the time for applying maintenance. The LTPP database has been a huge incentive for the production of many research results (Dong and Huang 2015; Gong et al. 2015). Using the data from the Specific Pavement Study 5 (SPS-5), Ahmed et al. (2013) evaluated the performance of a variety of rehabilitation strategies by analyses conducted on grouped and un-grouped data from the LTPP data base respectively. West et al. (2011) employed the data from SPS-5 experiment to investigate the performance of section with and without recycled asphalt pavements (RAP). In a similar study, Hong et al. (2010) investigated the long-term field performance hot mix asphalt containing (RAP) through data obtained from the LTPP SPS-5 test sections in Texas, which incorporated more than 16 years of data. According to the analyses on three typical distresses, ride quality, and rutting, they reported that the RAP sections showed more cracking while less severe rutting and similar roughness change over time. They concluded that a well-designed mix with as high as 35% of RAP can perform similarly to those sections without RAP.

Although extensive studies have been conducted on evaluating the pavement performance with field collected data. There is still a strong need to understand which data type plays a more critical role in the evolution of pavement serviceability, especially for those containing RAP materials. This study attempts to fill this gap by a comprehensive investigation of the various types of performance data from the LTPP database. The performance indicators included in the present study were distresses (including alligator cracking and wheel path longitudinal cracking), rutting, roughness (international roughness index, IRI).

DATA PREPARATION

In this study, only distress data from flexible pavements were considered. The distresses (cracks), rutting, roughness in terms of international roughness index (IRI), deflections from the falling weight deflectometer (FWD) tests, and back-calculated modulus of asphalt layers were retrieved from the LTPP database called InfoPave. In addition, the thicknesses of asphalt layers and the total thickness of pavement structures were obtained as well. Table 1 gives the data used and the sources of the data. The data used in this study were primarily focused on the SPS-5, which aimed to understand the efficacy of different rehabilitation strategies. It is noted that for some SPS-5 project sites, such as Florida and Montana, there is no control section, and the adjacent section from general pavement studies experiment was used. The index for the linked sections were obtained from GPS_SPS_LINK table, and these links could be found in the report by (Hall et al. 2002) as well.

Table 1. Source of data used

Data Element	Table
Distresses	MON_DIS_REV_AC
Rutting	MON_T_PROF_INDEX_POINT
IRI	MON_HSS_PROFILE_SECTION, MON_HSS_VISIT_NO
Deflection	FWD_DROP_DATA, MON_DEFL_TEMP_DEPTH, MON_DEFL_TEMP_VALUES
Modulus	BACKCAL_MODULUS, BAKCAL_PASS
Thickness	TST_L05B
Material types	TST_L05B, SECTION_LAYER_STRUCTURE
Linked GPS section	GPS_SPS_LINK
Rehabilitation history, SPS/GPS experiment labels	EXPERIMENT_SECTION

Table 2: SPS-5 Section Description (Core 9)

Section No.	Overlay Mix Type	Overlay Thickness (mm)	Milling
501 (Control)	NA	None	NA
502	30% RAP	51	No
503	30% RAP	127	No
504	Virgin	127	No
505	Virgin	51	No
506	Virgin	51	Yes
507	Virgin	127	Yes
508	30% RAP	127	Yes
509	30% RAP	51	Yes

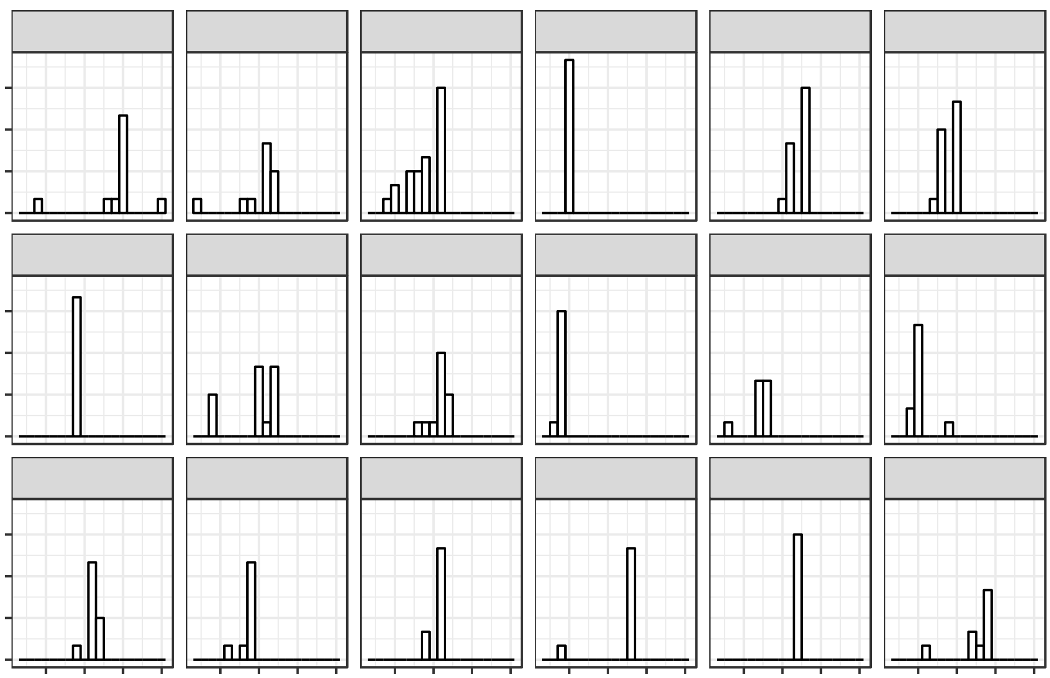


Figure. 1. Distress observations in each project of the SPS-5 experiment

SPECIFIC PAVEMENT STUDY 5 (SPS-5)

The SPS-5 was designed to study the different overlay rehabilitation strategies on the performance of flexible pavements. There is a total of eighteen projects in the Unites States and Canada. Each project has at least eight test sections and one control section, they were also referred to as the core-9 sections. Besides, there are several projects with varied number of supplemental test sections, for example, California included thirteen supplemental sections to study the effects of treatments such as polymer fabrics, Stone Mastic Asphalt (SMA), open graded mix on the performance of overlay rehabilitation. Other states such as Alabama, Arizona, Florida, Georgia, New Jersey have also included supplemental test sections into the SPS-5 experiment to study the performance of RAP used in overlay construction. The labels for the test