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Use of Chat-asphalt as a Paving Material: Field Performance Assessment

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Abstract: Field performance evaluation of a chat-asphalt test road is pursued through non-destructive testing, field inspection, and survey. Chat refers to mine tailings from the Tar Creek Superfund Site in Oklahoma, Kansas, and Missouri. A 960.1-m long test road was constructed near Cardin, Oklahoma using 80% raw chat in surface course and 50% raw chat in base course (both by weight of aggregate). Three non-destructive field tests, namely spectral analysis of surface waves (SASW), the falling weight deflectometer (FWD), and the ground penetrating radar (GPR) were conducted once immediately after construction and again after over two and a half years of service. The average FWD moduli of the surface and base layers were in the range of 841 to 1,751 MPa, which are lower than the traditional hot mix asphalt (HMA) moduli of 2,757.2 to 3,446.5 MPa. The combined back-calculated FWD modulus of surface and base chat-asphalt was found to be 1,379 MPa after construction, which increased significantly after over two and a half years. The results show that the SASW moduli are approximately five times higher than the corresponding FWD moduli. The HMA layer thicknesses obtained from the GPR match closely with the design thicknesses. The distress surveys showed a relatively low level of rutting and a fairly high level of smoothness. Overall, chat-asphalt is found to be a good paving material in this case study.

***Key words**: Asphalt; FWD; GPR; Modulus; Pavement; Surface wave; Tar creek chat.*

Introduction

The Tri-State Mining District in northeast Oklahoma, southeast Kansas, and southwest Missouri was the site of substantial zinc and lead ore extraction since the mid-19th century. This activity in Oklahoma resulted in a total of 150 million metric tons of mine tailings, called chat (i.e., chert fragments) in this study, of which approximately 68 million metric tons are currently stockpiled in large quantities on the surface of the Tar Creek Superfund Site [1, 2]. The stockpiled chat contains elevated levels of lead, zinc, and cadmium, raising potentially serious human health and ecological concerns. County chat roads (unpaved) create dust and serious health hazards. In 1993, Indian Health Services (IHS) data indicated approximately 35% of children tested in the Superfund area had elevated blood Pb levels, which is substantially dangerous to human health. Upon the recommendation of a state-level task force, named Tar Creek Superfund Task Force (TCSTF), a study was initiated to examine the use of chat as aggregates in roadway pavements.

Very few studies have been reported in literature on how certain types of aggregates perform when used in roadway paving. Generally, aggregate sources are tested for properties such as Los Angeles Abrasion, durability, and fractured face. Based on those test results, an aggregate source can be abandoned or accepted for producing asphalt concrete. Based on a two-year comprehensive bench-scale laboratory study, Wasiuddin *et al.* [2] concluded that Tar Creek chat could be used to produce asphalt roads of comparable quality. Consequently, a roadway test section was built to evaluate the field performance of chat. To that end, the present study evaluates the use of raw chat (also called pile-run chat in this paper) as an aggregate base of roadway pavements and examines the field performance of raw chat used as aggregates in hot mix asphalt (HMA) for paving applications.

As mentioned above, Wasiuddin *et al.* [2] conducted a two-year bench-scale laboratory study to develop mix designs using chat (from the Kenoyer North Pile) as one of the primary ingredients in HMA, called “chat-asphalt.” It was reported that as much as 80% and 50% raw chat (both by weight of aggregates) can be used safely in a surface course and a base course, respectively. Both chat-asphalt mixes met the Oklahoma Department of Transportation (ODOT) requirements for air voids and other volumetric properties as well as performance properties, namely moisture susceptibility, APA rut, and permeability in the laboratory. A suite of environmental tests was performed in the laboratory to examine the leaching potential of heavy metals (lead, zinc, and cadmium) in chat-asphalt surface and base mixes due to dry and wet rut tests and simulated milling. Tests indicated that chat-asphalt can be used safely as a roadway surface and base [2]. However, due to space limitation, laboratory materials, and environmental testing, data are not included in this paper. Rather the focus of this paper is field variation of modulus, distress, and/or performance of a roadway test section that was built using raw chat as aggregates.

Since field situations are different from laboratory situations in terms of scale, loading environment, and other factors, a field demonstration project was undertaken. As part of this demonstration project, a Test Road with stabilized chat as a base and chat-asphalt as a base course and a surface course was constructed near Cardin,

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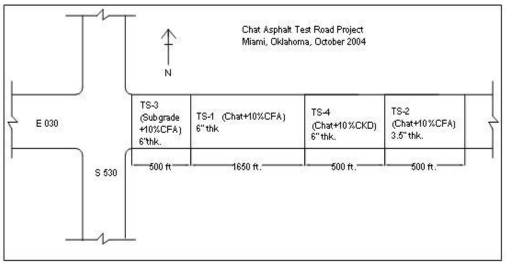
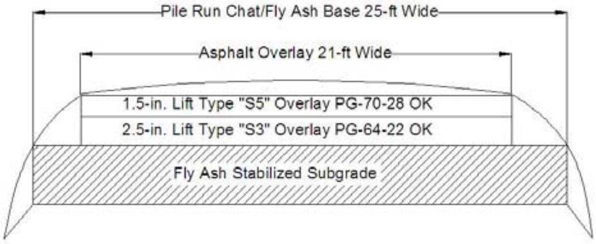
Fig. 1. Photographic View of the Test Road Before Construction.



(a) A Plan View



(b) A Section View

Fig. 2. Test Road Pavement Sections (1 ft. = 30.48 cm).

Oklahoma, and its performance was monitored for about three years. Significant field and laboratory tests were conducted as part of this monitoring process. Field activities included periodic visual inspections, distress surveys according to the AASHTO specifications, SASW, and FWD and GPR testing. Findings of this study are summarized in this paper.

Objectives

The overall objective of this study was to monitor and evaluate the performance of the chat-asphalt surface and base courses in the Test Road. The specific objectives are as follows:

1. Evaluation of in-situ modulus and thickness: perform non-destructive tests, namely FWD, SASW, and GPR immediately after the construction of the Test Road and after about three years of service.
2. Evaluation of smoothness: conduct a smoothness test according to the requirements of ODOT Special Provision 430-2QA.
3. Evaluation and monitoring of pavement distress: perform periodic visual inspection and distress survey according to the Federal Highway Administration (FHWA) guidelines, FHWA-RD-03-031.

The Test Road

A 960.1-m long county chat road (E30 starting from the intersection of S530 and E30 eastbound) in Cardin, Oklahoma was selected for field demonstration of chat-asphalt. Selection of this site was based on preliminary site visits by the research team, in cooperation with personnel from the Oklahoma Department of Environmental Quality (ODEQ), and it included such factors as existing roadway elevation, width, orientation, drainage, right of way, and proximity to other chat roads. A photographic view of the chat road before construction is shown in Fig. 1. The area surrounding the road is relatively flat, covered with large fields of soy bean and pasture. A close visual observation of the area revealed a lack of a well-defined drainage system. The 960.1-m long Test Road was divided into four different sections (TS-1, TS-2, TS-3, and TS-4), as shown in Fig. 2. The first section starting from the intersection of county roads S530 and E30, designated as TS-3, has a length of approximately 152.4 m. A typical profile of this section is shown in Fig. 2(b). The Test Road mixes were designed for more than 0.3 million equivalent single axle loads (ESALs). It consists of four layers. The top layer is 38.1 mm thick; it consists of type "S5" chat-asphalt containing 80% raw chat. The layer below is a 63.5-mm thick chat-asphalt of type "S3" [3]. This mix contains 50% raw chat blended with locally available limestone. The third layer has a thickness of 152.4 mm. It consists of subgrade soil stabilized with 10% class C fly ash (CFA). The bottom layer is the existing subgrade soil. It is basically fat clay having a liquid limit of 63 and plasticity index of 34, with some red brown mottles [4]. The second section starting from the east end of TS-3 is designated as TS-1. It has an approximate length of 502.9 m. This section is paved with the same chat-asphalt surface and base courses as in TS-3. The chat-asphalt surface course has a thickness of 38.1 mm, while the chat-asphalt base course has a thickness of 63.5 mm. These layers are overlaid on top of a stabilized-chat layer. The stabilized-chat layer has a thickness of 152.4 mm, and it consists of pile run chat stabilized with 10% CFA. The third section, designated as TS-4, starts from the east end of TS-1 and extends 152.4 m to the east. This section is essentially the same as TS-1, except cement kiln dust (CKD) is used as stabilizer instead of CFA. The fourth section, designated as TS-2, has a length of 152.4 m. This section is essentially same as TS-1 except the thickness of the chat-asphalt base layer is 127 mm instead of 63.5 mm, and the thickness of CFA stabilized-chat layer is 88.9 mm instead of 152.4 mm. The construction of the Test Road started on October 4, 2004, with the compaction of the existing subgrade and paving with chat-asphalt completed on November 14, 2004. Broadly, the construction of the Test Road was divided into three phases. The first phase consisted of grading, leveling, and compacting the existing subgrade. The second phase consisted of constructing the stabilized base, and the last phase involved paving the road with chat-asphalt base and surface courses.

The existing subgrade was graded, leveled, and compacted so that a reasonable conformity with the typical sections, grades, and density was achieved, as specified by ODOT [3]. Following the grading operation, the surface was compacted with the help of a vibratory roller. On average, two to three passes with strong vibrations and one pass without any vibration were needed to achieve the desired level of compaction. A nuclear density gauge was used to measure the in-situ density of the compacted subgrade. The field density from the nuclear gauge was compared with the laboratory moisture-density results. Raw chat was hauled from the Sooner Pile, located about 9.66 km from the Test Road site. The chat was spread with a motor grader on the compacted subgrade. Windrows, having a height of about 304.8 mm, were constructed with extra chat laid along the edges of the road using the motor grader blades to help protect CFA and CKD from wind. Altogether, about 1,933 tons (1,753.6 metric ton) of raw chat were utilized for the base course construction. CFA and CKD were hauled from Lafarge Corp. in Tulsa, unloaded, and spread with the help of a motor grader. A water tanker and a pulver mixer, also called a stabilizer were used for in-situ mixing of chat with CFA and CKD. A 12.7-metric ton vibratory roller was used to compact the stabilized-chat. A nuclear density gauge was used to check the quality of compaction. The results of the density tests showed a range of compaction between 88% and 95%, with an average compaction of approximately 94%. After compaction, the compacted stabilized-chat base was coated with an SS-5 emulsion (a slow-setting emulsion) to protect it from moisture infiltration and to assure a suitable environment for chemical reaction of stabilized chat. Prior to laying any chat-asphalt layer, the cured stabilized-chat base was first cleaned with the help of a mechanical broom. The chat-asphalt base course (S3-type mix) was laid first on the east bound lane and then on the west bound lane. After laying the mix, a vibratory roller was used for compaction. A pattern of two passes with a heavy vibratory mode and one pass with a static mode (no vibration) was followed by the vibratory roller to achieve the desired density. A light-duty roller was used for finish rolling. A nuclear density gauge was used to check the level of compaction. It was found that the field densities of the compacted chat-asphalt base course were in the range of 2,018.4 kg/m^3 (85% compaction) to 2,354.8 kg/m^3 (99% compaction), with an average density of 2,114.5 kg/m^3 (91% compaction), compared to the target density for the chat-asphalt base course of approximately 2,258.7 kg/m^3 (94% compaction). A tack coat was applied on the chat-asphalt base course before the construction of the surface course. An S5 type chat-asphalt mix was used for the construction of the surface course (3). The chat-asphalt surface course was laid on the west bound lane first starting from the east end of the project (from Section TS-2). A nuclear density gauge was used for checking the densities at regular intervals during construction of the chat-asphalt surface course. The densities of the compacted chat-asphalt surface course were found to be in the range of 1,874.2 kg/m^3 (80% compaction) to 2,338.8 kg/m^3 (99% compaction), with an average density of 2,114.5 kg/m^3 (90% compaction). Details of the construction process and the measurements are given by Wasiuddin *et al*. [4].

Non-Destructive Tests

Three non-destructive tests, namely SASW, FWD and GPR were performed in the field to analyze the performance of the chat-asphalt surface and base courses. The SASW and FWD tests were performed to measure the moduli of different layers in the pavement, while the GPR measurements indicated their thicknesses.

Falling Weight Deflectometer Test

The FWD test was conducted in accordance with the ASTM D 4694 test standard. The test was designed to apply two different magnitudes of load: 44.5 kN and 80 kN, and two different heights: 100 mm and 396 mm. Each load was impounded five times at each location. Deflections were measured with seven velocity transducers (sensors) that were mounted on a standard bar. The resulting deflections form a “basin” whose depth and shape were used to calculate the in-situ modulus (E_{FWD}) of the surface, base and subgrade layers [4, 5]. The FWD data were processed using the computer program, *Modulus 5.0*, developed by Liu and Scullion [6].

Because the thickness of the chat-asphalt surface course was relatively small, the flexural behavior of the chat-asphalt base and surface was not distinctly different. The FWD modulus values of surface and base courses are averaged and presented in Table 1. The modulus values varied between 689 MPa and 2,413 MPa with an average value of 1,400 MPa and a standard deviation (SD) of 490 MPa. From Table 1, it can be observed that the modulus obtained from the FWD data for Section TS-1 was approximately 1,751 MPa (with an SD of approximately 283 MPa), 1,255 MPa for Section TS-2 (with a SD of approximately 310 MPa), 841 MPa for Section TS-3 (with an SD of approximately 186 MPa) and 1,668 MPa for Section TS-4 (with a SD of approximately 538 MPa).

To examine the changes in the in-situ modulus with time, FWD tests were conducted at the same locations (Table 1) in 2005 and 2007. The back-calculated moduli, E_{FWD}, are summarized in Table 2. The E_{FWD} values are adjusted (to 20°C) for the purpose of comparison. Comparing Table 1 and Table 2, the E_{FWD} values of chat-asphalt (surface and base layer combined) show an increase with time, meaning the 2007 values are higher than the corresponding 2005 values. The level of increase in modulus varies between 29% to more than 700%, the eastbound lane showing larger increase than the westbound lane. Relatively high initial air voids (around 10%) might have led to additional compaction under traffic.

Also, it is possible that chat-asphalt mixes are more prone to aging-related stiffening than the traditional HMA. However, it should be noted that FWD tests are very sensitive, and one should not look at the actual moduli values rather consider the trend while interpreting these results. The subgrade moduli did not change substantially between the two testing periods.

SASW (Spectral Analysis of Surface Waves) (2005)

As mentioned previously, SASW is a non-destructive field test, which was performed in this study to evaluate the in-situ modulus of different layers of the pavement sections. The SASW test is also useful in determining the profile of a pavement structure. This method was developed by Nazarian *et al*. [7] to determine small strain Young’s modulus profiles of pavements and small strain shear modulus profiles of soils. The method is based on the dispersive characteristic of Rayleigh waves when traveling through a layered medium. The SASW test is performed on the surface, allowing for less expensive measurements than with traditional borehole methods [5].

Table 1. FWD Back-Calculated Moduli for Chat-Asphalt Base and Surface Courses.

Section ID	Dist. From East End (m)	E_{FWD} of HMA Layer (MPa)				Average (MPa)	Std. Dev. (MPa)
		East Bound		West Bound			
		44.48 kN	80.07 kN	44.48 kN	80.07 kN		
Section TS-2	15.24	1737.48	1516.85	1082.48	1137.63	1254.85	310.26
	30.48	1179.00	1096.27	-	-		
	45.72	999.74	1020.42	965.27	882.53		
	60.96	910.11	951.48	-	-		
	76.2	1365.16	1523.74	1310.0*	1316.9*		
	91.44	1275.53	1275.53	-	-		
	106.68	-	-	2144.3	1785.74		
	121.92	1282.42	1082.48	-	-		
	137.16	-	-	1110.06	1082.48		
Section TS-4	167.64	-	-	2164.95	2082.22	1668.53	537.79
	182.88	2433.84*	2227*	-	-		
	198.12	-	-	1799.53	2330.43		
	213.36	1730.58	1675.43	-	-		
	228.6	-	-	1241.06*	1110.06*		
	243.84	1220.37	1613.37	-	-		
	259.08	-	-	944.58	1061.79		
	274.32	2185.64	2233.90	-	-		
	289.56	-	-	923.9	1048.0		
Section TS-1	342.9	1854.69	1496.16	-	-	1751.27	282.69
	381	-	-	1861.58	1640.95		
	419.1	1310.00	1392.74	-	-		
	457.2	-	-	1585.79	1323.79		
	495.3	1496.16	1585.79	-	-		
	533.4	-	-	1799.53	1689.21		
	571.5	1847.79	1854.69	-	-		
	609.6	-	-	2358.0	2033.95		
	647.7	1806.43	1909.85	-	-		
	685.8	-	-	1668.53*	1565.11*		
	723.9	2227.01*	2344.22*	-	-		
	762	-	-	1730.58	1703.01		
Section TS-3	822.96	-	-	592.95	648.11	841.16	186.16
	838.2	648.11	689.48	-	-		
	853.44	-	-	820.48	875.63		
	868.68	951.48	985.95	-	-		
	883.92	-	-	744.63	834.27		
	899.16	944.58	1041.11	-	-		
	914.4	-	-	799.79	854.95		
	929.64	655.00	668.79	-	-		
	944.88	-	-	1137.63	1261.74		

* - Field cores were retrieved at these locations for laboratory M_R tests.

The SASW test consists of striking the surface of a pavement with a hammer and recording the resulting stress wave-time histories using two receivers (geophones) at known offsets or distances. SASW tests were performed at three selected locations on the Test Road. Different sizes of hammers were used for different source-receiver geometries so that different wavelengths are achieved. Also, spacing between the receivers was varied to sample different pavement layers. The wave arrival histories at different spacing were analyzed to determine the pavement layer thicknesses and moduli. Once the shear wave velocity profiles are known, shear and Young's modulus of the materials (E_{SASW}) are calculated using mathematical equations [8]. The equations are incorporated in the *WinSASW*, a computer program developed at the University of Texas at Austin. This software was used in this study to evaluate the aforementioned properties.

A summary of the test results is presented in Table 3. It is observed that the HMA base layer modulus is higher than the surface layer modulus. This is consistent with the laboratory indirect

Table 2. Comparison of Moduli from FWD Tests.

Section ID	Station (m)	Lane	Asphalt Thickness (cm)	Base Thickness (cm)	Asphalt E_{FWD} @ 20°C (2005) (MPa)	Asphalt E_{FWD} @ 20°F (2007) (MPa)	Subgrade E_{FWD} (2005) (MPa)	Subgrade E_{FWD} (2007) (MPa)
Section TS-2	15.24	WB	13.00	7.92	1634.06	4433.33	82.74	75.84
	15.24	EB	16.05	8.66	2220.11	14740.99	126.17	123.42
	30.48	EB	16.05	8.66	1971.90	16188.89	69.64	95.15
	45.72	WB	13.00	7.92	1682.32	3178.48	72.39	98.60
	45.72	EB	16.05	8.66	1799.53	8411.60	73.08	93.77
	60.96	EB	16.05	8.66	1399.64	3833.49	75.84	85.49
	75.90	EB	16.05	8.66	2392.48	3116.43	62.74	96.53
	76.20	WB	13.00	7.92	2178.74	11693.51	68.95	76.53
	91.44	EB	16.05	8.66	2337.32	6984.39	75.15	84.81
	106.68	WB	13.89	13.36	2861.32	4419.54	54.47	62.74
	121.92	EB	16.05	8.66	2151.16	6163.91	58.61	70.33
	137.16	WB	13.89	13.36	1647.85	3371.54	42.75	55.85
Section TS-4	167.64	WB	11.89	14.73	3585.27	7218.81	69.64	88.25
	182.88	EB	12.95	15.85	4722.91	20987.64	57.92	73.77
	198.12	WB	11.89	14.73	23304.28	21649.54	70.33	140.65
	213.36	EB	12.95	15.85	3502.54	9790.56	53.78	84.12
	228.60	WB	11.89	14.73	1792.64	2916.48	51.71	73.08
	243.84	EB	10.29	15.82	3578.38	7887.60	95.15	109.63
	259.08	WB	11.89	14.73	3950.70	12686.35	71.02	124.80
	274.32	EB	10.29	15.82	5343.44	7087.81	103.42	123.42
	289.56	WB	11.89	14.73	1358.27	2102.90	46.88	54.47
Section TS-1	381.00	WB	11.71	14.33	2833.75	5812.28	68.26	91.01
	457.20	WB	11.91	15.80	2275.27	3516.33	51.02	55.85
	533.40	WB	11.91	15.80	2785.48	5653.70	55.85	68.95
	609.60	WB	11.91	15.80	3736.96	5026.28	52.40	66.88
	685.80	WB	11.91	15.80	2785.48	4247.17	59.29	71.02
	762.00	WB	12.07	17.12	2813.06	5322.75	44.13	71.02
Section TS-3	822.96	WB	12.07	17.12	1523.74	4688.43	43.44	72.39
	838.20	EB	12.65	16.00	1151.42	4867.70	53.09	84.81
	853.44	WB	12.07	17.12	2061.53	4695.33	46.88	82.05
	868.68	EB	12.65	16.00	1585.79	4716.01	59.98	99.97
	883.92	WB	12.50	14.00	1578.90	3585.27	33.78	72.39
	899.16	EB	12.65	16.00	1558.22	5074.54	46.19	77.22
	914.40	WB	12.50	14.00	1647.85	3019.90	33.78	66.19
	929.64	EB	12.65	16.00	1075.58	3192.27	48.95	79.98
	944.88	WB	12.50	14.00	1958.11	3357.75	25.51	60.67

tension resilient modulus test results, which show higher modulus values for the chat-asphalt base mix [4]. From Table 3, it can be observed that Section TS-2 showed a comparatively high E_{SASW} of 8,674 MPa for the chat-asphalt surface course and 9,308 MPa for the chat-asphalt base mix. While Sections TS-1 and TS-4 showed similar SASW moduli, 4,895 MPa and 4,275 MPa for the surface mix and 6,412 MPa and 5,309 MPa for the base mix, respectively.

A comparison of both FWD and SASW field moduli is also presented in Table 3. The results show that E_{SASW} is approximately four times higher at TS-4 and six times higher at TS-2 than the E_{FWD}. This is consistent with the study by Nazarian *et al.* [8] who reported that the moduli of HMA layers obtained from FWD data exhibit, in general, greater variations than those of SASW test data. Nazarian *et al.* [8] also reported that the difference is due to the lack of sensitivity of the FWD test method to the stiffness of the top thin layer, while the SASW method is quite sensitive in this region. Another important reason for such differences is the strain level. Strain level in SASW is much lower than the strain level (from deflection basins) in FWD.

Ground Penetrating Radar (GPR)

A Ground Penetrating Radar (GPR) test was used to determine the thicknesses of the pavement structure in 2005 and 2007. The GPR is a pulse-echo method for measuring pavement layer thicknesses [9]. It works like an ultrasound device, but it uses radio waves rather than sound waves to penetrate the pavement [9]. Antennas mounted on a moving truck are used to transmit short pulses of radio wave energy into the pavement. As this energy travels down through the pavement structure, echoes are created at boundaries of dissimilar materials. The arrival time and strength of these echoes are used to calculate pavement layer thickness [10].

Table 3. Comparisons between FWD and SASW Moduli.

Layer	Modulus, E_{SASW} (MPa)			Thickness (cm)		
Profile	TS-2	TS-4	TS-1	TS-2	TS-4	TS-1
HMA Surface	8670.16	4257.51	4878.04	3.66	3.66	3.66
HMA Base	9307.92	5326.20	6412.12	12.19	6.10	6.10

Location	E_{FWD} (MPa)			E_{SASW} (MPa)		
ID	Load		Avg	Surface	Base	Avg
	44.48 kN	80.07 kN				
8 (TS-4)	1241.06	1110.06	1179.00	4260.96	5329.65	4791.86
38 (TS-2)	1365.16	1523.74	1447.90	8673.60	9307.92	8990.76

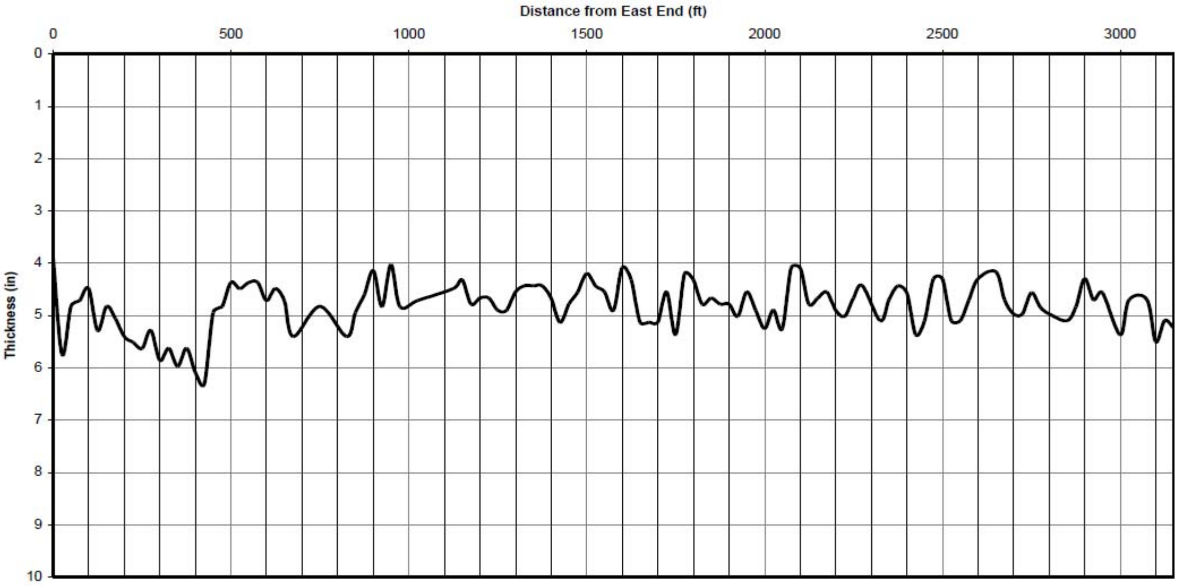


Fig. 3. GPR Thickness Profile for Westbound Lane (2005) (1 in. = 2.54 cm).

The results of GPR tests from the westbound lane are shown in Fig. 3. For relatively similar mixes, the GPR data cannot differentiate between the chat-asphalt surface and base layers [11]. Therefore, the results shown in Fig. 3 represent the combined thickness of the chat-asphalt surface and base courses. The thickness profile of the eastbound lane varies between 100 mm to 150 mm, while that of the westbound lane varies between 100 mm to 140 mm. By combining both westbound and eastbound lanes, the average thicknesses of chat-asphalt base and surface layers were found to be 11.8 mm, 147.3 mm, 124.5 mm, and 119.4 mm for Sections TS-1, TS-2, TS-3, and TS-4, respectively. The design thickness for Section TS-2 was 165 mm, while for the remaining sections (TS-1, TS-2, and TS-4), the design thickness was 100 mm. From these results, it is evident that the thicknesses of the chat-asphalt base and surface courses obtained from the GPR data were fairly consistent and comparable to the respective design thicknesses. Only Section TS-2 showed a high variation. This may be due to the inconsistencies of thickness profile during construction. The HMA thickness profile of the test site was also obtained from the SASW analysis. The results are shown in Table 3. From the thicknesses reported in this table, other than the chat-asphalt base thickness of Section TS-2, the thickness values of each layer in sections TS-2, TS-4, and TS-1 compared favorably with the SASW results.

A GPR test was conducted again on October 30, 2007. The corresponding thickness profiles for the westbound lane are shown in Fig. 4. Comparing Fig. 3 and 4, the thickness profiles obtained from the GPR tests in 2005 and 2007 match closely. A similar trend was observed for the eastbound lane [4].

Pavement Inspection (March 2006)

Before milling and repaving a portion of the Test Road, the pavement was inspected for any visible distress. Photographs were taken at these locations. Overall, the pavement was in a very good condition and did not exhibit any major distresses such as fatigue and rutting. Some longitudinal cracks were observed between 443.5 and 449.6, 557.8 and 563.9, 757.1 and 762.0, and 763.8 and 792.5 m, respectively, from the east end. Some permanent deformation was observed in the westbound lane between 106.7 and 114.3 m, respectively. Between 542.5 and 548.6 m, respectively, edge cracks and minor settlements were observed.

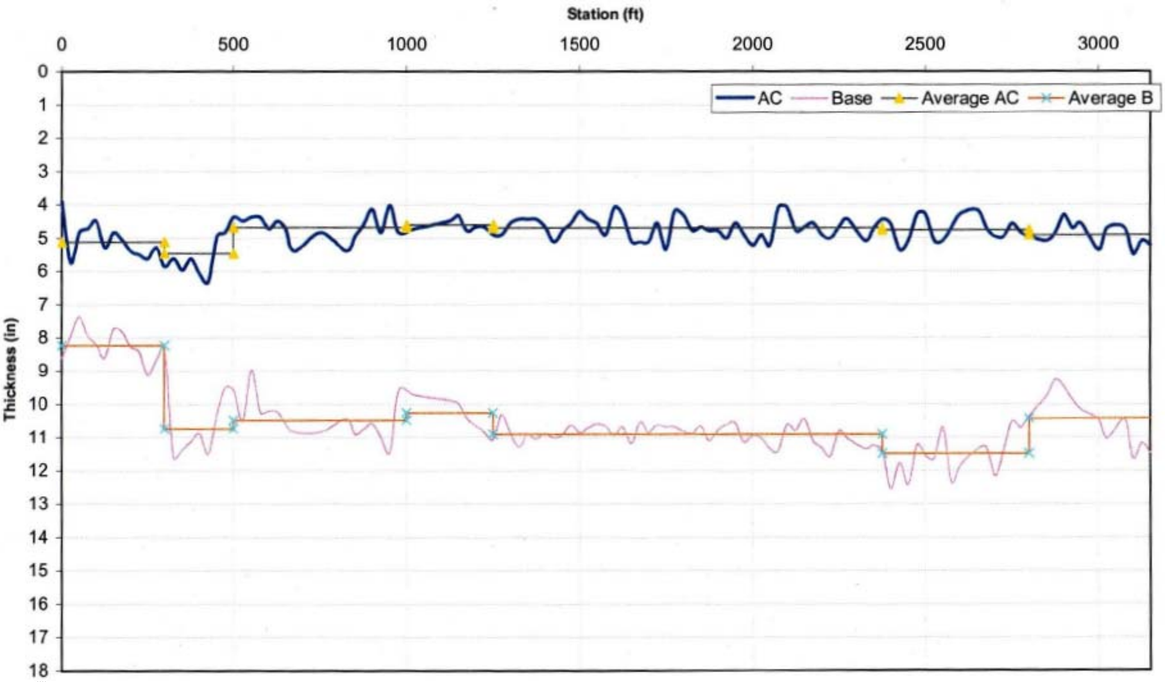


Fig. 4. GPR Thickness Profile for Westbound Lane (2007) (1 in. = 2.54 cm).

Table 4. Results of Profilograph Testing.

Direction	From	To	Distance (m)	Profile Index (cm/ 1.6 km)
Eastbound	31+77	49.02	160.93	49.02
	26+49	45.47	160.93	45.47
	21+21	45.47	160.93	45.47
	15+93	59.69	160.93	59.69
	10+65	50.55	160.93	50.55
	5+37	85.42	130.15	85.42
			Average	54.97
Westbound	31+77	80.04	130.15	80.04
	27+50	43.69	160.93	43.69
	22+22	30.99	160.93	30.99
	16+94	44.96	160.93	44.96
	11+66	77.72	160.93	77.72
	6+38	40.39	160.93	40.39
			Average	52.10

Distress Survey

No maintenance work was performed on the Test Road between construction in November 2004 and January 2007. An inspection was conducted in January 2007. In general, the Test Road was found to do well after more than two years in service. TS-2 having the thinnest stabilized base experienced the maximum distress (transverse cracking), as expected.

After the Test Road was in service for about two and a half years, a detail distress survey was conducted in June and July 2007. Specifically, the survey was focused on the: (1) evaluation of the smoothness of the pavement and (2) evaluation of distresses.

Evaluation of Smoothness

An Ames profilograph, having a 7.6-m long beam (reference plane), was used to measure smoothness. A separate movable wheel located in the center of the beam measures the vertical deviations from the reference plane. The deviations are accumulated and converted to a reading in centimeter per kilometer. ODOT Special Provision 430-2QA provides specifications for the equipment, the testing procedure, and the smoothness requirements for different classes of roadways. The profilograph was calibrated on-site, and one pass was made in the inside wheel path in both directions. The profilograph traces actually ran from station 1+10 to station 31+77. The traces did not include the 30.9-m long milled and replaced section on the east end of the project.

Table 4 summarizes the results of the profilograph testing. The profilograph data was analyzed using a standard 5.08-mm blanking band. The high point in each bump and the low point of each dip is measured by the profilograph. Deviations over 5.08 mm from the reference plane are summed for each 0.16 km section. From Table 4, the average Profile Index is similar for each direction.

Although the average measured profile indices were in excess of the ODOT “unacceptable” range, it should be noted that the Test Road pavement is not the type of project to which smoothness specifications would apply. Furthermore, since there were no smoothness specifications in place at the time of construction, the extra level of care in subgrade preparation was not taken into account by the contractor. For county roads, the motor grader operator typically prepares the subgrade by a visual estimate only. In highway construction, however, a survey crew would be dispatched to set stakes marking the exact grading elevations. This operation is referred to as “blue-topping.” The important evaluation is that the project felt smooth when simply driven over at normal speed, especially in comparison to the surrounding gravel roads.

Table 5. Distress Summary.

Code	Distress Type	Total Quantity
3L	Edge cracking, low severity	61.63 m
3M	Edge cracking, moderate severity	3.11 m
4bL	Longitudinal cracking outside of wheel path, low severity	21.37 m
6L	Transverse cracking, low severity	0.73 m
7L	*Patching, low severity	207.59 m^2
n/a	4” cores	13
n/a	6” cores	22

** All but 0.14 square meter of patching was an intentional mill and fill.*

Pavement Distress Survey

A distress survey was performed on July 6 and 7, 2007, according to FHWA publication FHWA-RD-03-031, *Distress Identification Manual for the Long-Term Pavement Performance Program*. The first part of the survey involved laying out a visible reference system. A Roll-a-Tape was used to measure out stations in 3-m intervals for the entire length of the Test Road. After the stations were marked, rut measurements were taken at 15.2-m intervals using a 3-m straight edge and a notched wedge. The notches were cut at 2.54-mm intervals. Using 15.2-m intervals, ruts were measured at 64 stations along the Test Road. At each station, ruts were measured in four places, the inside and outside wheel path of each lane. Therefore, a total of 256 individual rut measurements were made. Overall, the Test Road had insignificant rutting after over two and a half years in service. Generally, pavements receive the vast majority of their rutting during the first two summers in place [12].

The eastbound lane exhibited lower rut than the westbound lane, with an average of 20.3 mm in each wheel path. The deepest rut measured in the eastbound lane was 5.1 mm. There were only two stations having a rut over 2.5 mm. Out of the 64 stations measured, 15 had no discernable rutting in either wheel path. The westbound lane averaged 4.8 mm of rutting in the inside wheel path and 3.3 mm of rutting in the outside wheel path. The deepest rut was in the inside wheel path at station 30+50, measuring 12.7 mm. While there were only two stations in the westbound lane that exhibited no discernable rutting, there were 23 in which the ruts were no deeper than 2.5 mm. The disparity between the measured rut depths can likely be attributed to the construction sequence. Back in November of 2004, the project was constructed on the first dry day after several days of rain. The conditions were wet, and the chat-asphalt was laid in the eastbound lane first. The westbound lane received more construction traffic, in the form of dump trucks loaded with 13.6 metric ton of chat-asphalt each, on its prepared subgrade. The subgrade had a small degree of rutting in the westbound lane before any HMA was laid. According to ODOT specifications, the maximum allowable rut for pavements with less than 0.3 million ESALs is 8.1 mm. Based on this criterion, 99% of the rut measurements met this criterion.

The final part of the distress survey involved walking the project and marking the distresses described in FHWA-RD-03-031 on the grid sheets. At 15.2 m per sheet, a total of 64 grid sheets were prepared. Table 5 summarizes the distresses found on the entire Test Road. The distress code, type, and quantity are shown in Table 5. For example, the longitudinal distress of the Test Road is coded as 4bL. As can be seen in the fourth of this table, longitudinal cracks are designated by “4” and cracks outside the wheel path are designated by “b.” Here “L” represents low severity cracks (less than 6 mm). Overall, an insignificant level of transverse cracking was observed. Minor patching and rutting were also encountered on the project. Almost all of the patching was due to milling and repaving as part of the environmental investigation. Distresses such as fatigue cracking, block cracking, reflection cracking, potholes, shoving, bleeding, polished aggregate, raveling, lane-to-shoulder drop-off, water bleeding, and pumping were not observed.

Conclusions

A field study was undertaken to evaluate the performance of chat-asphalt having raw chat from the Tar Creek Superfund site. After over two and a half years in service, the chat-asphalt pavement with 80% raw chat in surface course and 50% raw chat in base course exhibited very good performance, in an overall sense. The specific conclusions are given below:

1. The HMA layer thicknesses obtained from the GPR data are fairly consistent and close to the respective design thicknesses. Only TS-2 exhibited a slightly higher variation.
2. The average FWD back-calculated moduli for the Test Road is approximately 1,751 MPa for TS-1, 1,255 MPa for TS-2, 841 MPa for TS-3, and 1,668 MPa for TS-4. These values are in low to moderate range of typical HMA modulus, which is about 2,757 MPa. Compaction might have played a significant role in this regard. The FWD moduli in 2007 are comparatively higher than those of 2005.
3. The SASW moduli for TS-2 is approximately 8,618 MPa for the surface course and 9,308 MPa for the base course. The corresponding values for TS-1 and TS-4 are 4,895 MPa and 4,275 MPa for the surface course and 6,412 MPa and 5,309 MPa for the base course, respectively. Overall, the E_{SASW} values are approximately four times higher at TS-4 and six times higher at TS-2 than the corresponding E_{FWD} values.
4. The level of rutting is low for the Test Road after over two and a half years in service. The average rut in both wheel paths of the eastbound lane is only 2 mm. The average rut of the westbound lane is 4.8 mm in the inside wheel path, and 3.3 mm in the outside wheel path.
5. The distress level is relatively low and the smoothness is good after nearly two and a half years in service indicating that chat-asphalt is a viable paving material.

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