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Hot In-Place Asphalt Recycling for Small Repairs on Airfields in Remote Settings

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Abstract: This paper presents results from an evaluation of Hot In-Place Recycling (HIR) techniques for conducting small repairs of aged asphalt concrete (AC) pavements on airfields in remote locations. The evaluation included both laboratory and field testing. In the laboratory, four different types of rejuvenators were evaluated using the Asphalt Pavement Analyzer (APA) test and the Dynamic Shear Rheometer (DSR) test to investigate the use of rejuvenators to soften aged binder obtained from a reclaimed asphalt pavement (RAP) material. The use of small quantities of Type I portland cement during the mix rejuvenation cycle was also explored. Optimum dosage rates for the four types of rejuvenators tested were developed, and the best performing rejuvenator-dosage rate combination was selected to use for field trials. A series of full-scale repairs were conducted using HIR technology, rejuvenators, cement, and two RAP materials. The performance of the repairs was evaluated under simulated F-15E aircraft traffic. All repairs met the objective of 3,500 passes of F-15E aircraft, and the extracted binder from the repairs showed signs of rejuvenation, which could result in longer lasting repairs.

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Key words*: Airfield repair; Asphalt recycling; APA; Full-scale; Rejuvenators.*

Introduction

Conducting small-sized repairs on aged asphalt concrete (AC) airfields in remote locations can be technically and logistically challenging. One alternative available is using Hot In-place Recycling (HIR) techniques. Typically HIR uses some amount of virgin material, but the investigation described in this paper deals specifically with the reuse of existing material. This type of recycling eliminates the need to bring in or store any virgin repair materials on-site. Airfield repairs must be of sufficient quality to withstand trafficking of aircraft loads with high tire pressures, and the asphalt binder in many of these locations exhibits considerable aging. Rejuvenation of the binder as a part of the HIR process is necessary in order for repairs to last as long as possible.

The use of rejuvenators as spray-on surface seals to extend the life of asphalt pavement surfaces has been popular for many years since it is one of the lowest cost preventative maintenance practices [1-2]. Research has also been conducted to explore the feasibility of using spray-on seals for airfield pavements [3]. Now that different methods of asphalt recycling are in use in the highway industry [4], many research groups have begun investigating the concept of rejuvenating asphalt binders within reclaimed asphalt pavement (RAP) by mixing different types of rejuvenator products in with RAP material during the HIR process. Rejuvenators have been shown to reduce the stiffness of 100% RAP mixes and improve creep compliance [5]. The use of rejuvenators in the conventional HIR process in Ontario, Canada has been documented, and an increase in the PEN values was reported, indicated a softening of the RAP binder [6]. An important factor that needs to be considered is that while adding rejuvenator to RAP can soften the binder, adding too much can decrease the rutting resistance below acceptable levels [7]. Therefore, determination of an optimum dosage rate for a specific RAP material is necessary to extend the life of the pavement without increasing rutting potential.

Cementitious materials could be an option for stiffening binder that has been overly rejuvenated. Asphalt moisture susceptibility research has included the use of cementitious materials to stiffen asphalt binder [8-9]. Hydrated lime has been the preferred cementitious filler due to its ability to reduce moisture susceptibility. Hydrated lime has also been reported to stiffen binder more than other cementitious fillers such as cement kiln dust (CKD) [8]. CKD behaves similarly to portland cement [10]. Due to increased binder stiffness, the use of hydrated lime has been shown to increase rutting resistance [9]. Hydrated fillers in general can stiffen asphalt binder more readily than other cementitious fillers because hydrated fillers can interact with binder chemically and physically [11]. However, in remote locations ordinary Type I portland cement may be more readily available as a candidate for stiffening binder during repairs that employ HIR.

Due to equipment constraints that were a part of this investigation, a small-sized repair was considered to be 20 to 50 square feet at a depth of 6 inches. Airfield repair equipment for military use is typically stored in shipping containers, which limits the size of milling machines, mixing devices, infrared heaters, material handling equipment, and compactors. These limitations affected the repair procedure developed as a part of this research and caused the objective to be centered on repairing a relatively small amount of pavement at one time.

The objective of the work described in this paper is to determine the feasibility of using HIR to conduct small repairs of aged AC on airfield pavements without using additional virgin asphalt material and to determine if rejuvenators can soften RAP binder as a part of

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the HIR process in order to extend the life of the repairs as much as possible. Data are presented from a laboratory evaluation of four different types of rejuvenators using the Asphalt Pavement Analyzer (APA) to determine rut resistance and the Dynamic Shear Rheometer (DSR) to ascertain the effect of the rejuvenators on the binder properties of the RAP material. Type I portland cement was also investigated for use as a stiffening agent if rejuvenator use causes a decrease in rutting resistance that is outside acceptable levels. Optimum rejuvenator dosage rates were determined for each type of rejuvenator. The best performing rejuvenator based on laboratory testing was selected for field trials, as was the best performing rejuvenator-cement dosage combination. Full scale 4-ft by 6-ft repairs were conducted using HIR and two RAP materials. One RAP material was the same one used to determine optimum rejuvenator contents, while the other RAP had not been previously tested with rejuvenators in the laboratory. Repairs were trafficked with an F-15E military jet aircraft wheel loaded to 35,500 lb with a high tire pressure (325 psi). Results were used to evaluate the overall feasibility of using HIR technology to conduct small airfield repair in remote locations.

Laboratory Evaluation

Materials

Reclaimed Asphalt Pavement

Samples of reclaimed asphalt pavement (RAP) material were collected from two test sites for characterization. These materials are hereafter referred to as RAP-1 and RAP-2. RAP-1 was used to determine the optimum rejuvenator and rejuvenator content in the laboratory before field verification. In contrast, RAP-2 was used to simulate an austere environment where laboratory equipment is not available and a generally accepted rejuvenator content could be used during HIR of airfield pavements. Slab samples of RAP-1 were collected for the laboratory evaluation portion of this study. Core samples were collected from both test sites for mix characterization via aggregate testing. The aggregate material was tested to determine specific gravity according to AASHTO T 84 and AASHTO T 85. Gradation was determined in accordance with AASHTO T 30. Core samples of RAP-1 were obtained for baseline testing using the Asphalt Pavement Analyzer (APA), and the results are discussed later in this paper. The asphalt binder was extracted and recovered from the RAP-1 core samples per AASHTO T 164 and T 319 for Dynamic Shear Rheometer (DSR) testing in accordance with AASHTO T 315. A visual inspection of the test site where RAP-1 was obtained revealed an oxidized and brittle pavement with high-severity raveling. This distress made this test site a prime candidate for an evaluation of HIR techniques. RAP-2 consisted of a newer, but aged pavement without critical distresses. Fig. 1 shows the average aggregate gradation curve obtained for both RAP materials and the properties measured. Both gradations generally met the airfield specification band.

Slabs of RAP-1 material used for the rejuvenator evaluation were processed for further testing as follows. The slab samples were first washed to remove the base course material to keep it from impacting the original mix gradation and then allowed to dry to their

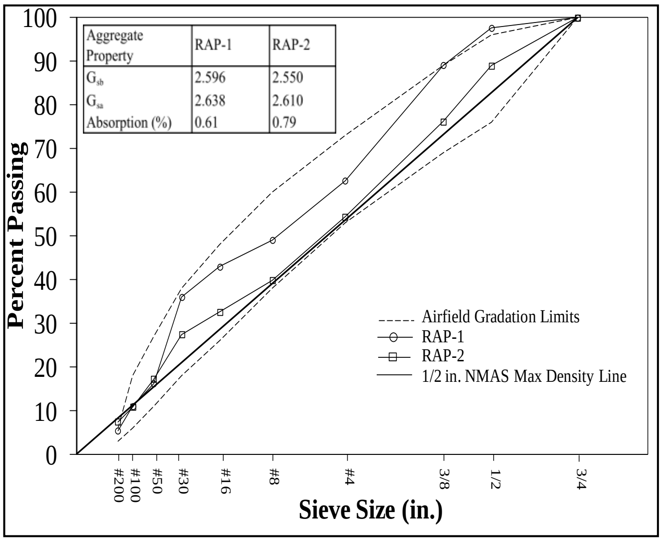


Fig. 1. Recycled Asphalt Pavement (RAP) Gradation Curves.

original states. The samples were then placed into a large batching oven and heated at 300°F for four hours. The pavement samples consisted of two layers, and the upper layer was very oxidized and stiff. Due to its heavy oxidation, the top 1 to 1.5 in. of material was separated from the remaining materials and placed back into the oven for an additional hour. The lower section was easily crumbled into a workable size for separation and testing. After the additional hour in the oven, the upper layer was broken down into the smallest size possible and cooled. The total sample was recombined and run through a large sample shaker to separate any material larger than 1 in. Any material greater than 1 in. was reheated to 300°F for 2 hours and further reduced to the desired size of less than 1 in. The complete sample was then split using an asphalt sample splitter and reduced to 70- to 80-lb lots.

Rejuvenators

Four different types of rejuvenator products were selected for laboratory testing. CRF® is a maltene based, petroleum oil and water cationic emulsion typically used as a restorative seal. Cyclogen LE® is an asphalt emulsion designed to return maltenes to oxidized asphalt binder during cold in-place recycling (CIR) or HIR processes. Viplex 50 is a petroleum distillate based product also used as a surface sealer. Rejuvaseal® is made from coal tar, aromatic oils, and specialty solvents, and is typically used as an asphalt surface sealer. According to the U.S. Geologic Survey (USGS) coal tar based sealers could be carcinogenic [12]. Of the sites testes by the USGS, some sites where a coal tar based sealer had been used showed higher levels of the cancer causing polycyclic aromatic hydrocarbons (PAHs) than unsealed areas, where other sites showed similar levels of PAHs for sealed and unsealed pavements. The USGS concluded that further research into the human health risk of coal tar based sealers is warranted. CRF®, Cyclogen LE®, and Rejuvaseal® were diluted 1:1 (one part product to one part water) and were cured for 1 hour at room temperature per the manufacturer's instructions. The curing occurred after dilution with water but before mixing with the RAP material. Viplex 50 was used neat without dilution. The rejuvenators were directly mixed into heated RAP material to simulate the same process that would be used in the field. Various dosage rates were tested based on preliminary testing. During field testing, the rejuvenators were diluted prior to testing, so they experienced at least one hour of cure time.

Laboratory Test Methods

Specimen Preparation and Compaction

Samples of approximately 7.3 lb of the RAP-1 material were heated to 140°F and then placed in a mixer for 1 minute. If cement was being tested, it was added by total weight of RAP and mixed for one additional minute. The rejuvenator was then added, and mixing continued for 2 minutes. Once mixing was completed, the batch was returned to the oven for 30 minutes to re-establish the compaction temperature (140°F). For compaction, 6.6 lb of material was poured into a 5.9-in. diameter mold for compaction. The specimens were compacted to 7.0 ± 0.5 % voids and a specific height of 3.0 ± 0.1 in. using a Rainhart gyratory compactor. Two specimens were compacted at each rejuvenator dosage rate for replication. In addition, two samples of the rejuvenated mixture were set aside from each lot for maximum theoretical specific gravity testing per ASTM D 2041. The compacted specimens were allowed to cool over night, and bulk specific gravity testing according to ASTM D 2726 was performed the following day. The target air void content was determined to be 7% and calculated in accordance with ASTM D 3203. The mixing and compaction temperatures were considerably lower than would be used for hot-mix asphalt (HMA) laboratory testing. The lower temperature was used in order to simulate expected field conditions. Since the existing pavement would be heated using an infrared heater in order to remove the pavement, the research team expected the residual heat and the addition of a rejuvenator to soften the mixture enough to compact the recycled mixture and achieve the target density without additional heating. By not adding additional heat, no further oxidation of the rejuvenated binder would occur, resulting in a longer lasting field repair. The mixing temperature of 140°F was sufficient for laboratory compaction. However, as discussed in the Repair Construction Methods section of this paper, mixtures in the field required additional heat in order to achieve the target density during compaction.

Two six-inch diameter core samples were taken from the test site where RAP-1 was obtained. Both core samples were trimmed down to a height of 3 in., and APA testing was conducted on the uncut face of the cores to represent the rutting behavior of the existing asphalt pavement material without rejuvenator. The testing surface was the original pavement surface.

Asphalt Pavement Analyzer (APA) Testing

Rutting potential was evaluated using the APA test in accordance with AASHTO TP 63. The APA simulates single-wheel vehicle traffic using pneumatic rubber hoses and steel-wheel loading. The APA is used to compare relative rutting performance between specimens and cannot be used for direct comparison to actual field results. All data gathered during the testing were collected and tabulated for indexing purposes only. The molds were pre-heated to the test temperature (147°F) for six hours prior to the test, while the specimens were stored at room temperature before testing. Paired specimens of the same rejuvenator dosage were placed into the APA. The maximum vertical wheel depth and load were calibrated prior to testing. The hose pressure was initially varied to determine an optimum pressure that would prevent premature specimen failure. It was imperative that the optimum pressure was set to provide useful data points based on rejuvenator type and dosage rates. The test hose pressure for this experiment was set to 150 psi, and the load level was standardized at 100 lb. Specimens were placed in the APA, and tested for 8,000 cycles.

Asphalt Binder Properties

DSR testing was conducted on samples of asphalt binder that were extracted and recovered from the APA specimens. The binder extracted from the original pavement was taken from a representative sample of the processed RAP. As previously described, the RAP for laboratory testing (RAP-1) was obtained from a pavement structure with two distinct layers: the heavily aged surface layer and the underlying layer which appeared to be aged to a lesser degree than the upper layer. After processing, the two layers were combined before extraction. Therefore, the binder extracted was a mixture of the binder obtained from these two layers. For this project, the DSR test was conducted to evaluate the effect of the rejuvenators on the viscoelastic properties of the asphalt binder. The binder specimens were aged at 325°F in the Rolling Thin-Film Oven (RTFO) (AASHTO T 240). Typically the RTFO is used to simulate the oxidation of hot mix asphalt during production, but in this case, the RTFO was used to attempt to simulate any oxidation that would occur when the infrared heater was used to heat the aged asphalt before removal during field testing.

Laboratory Test Results and Discussion

Rutting Potential

The average maximum rut depth of the compacted specimens for each of the recycled mixes is presented in Fig. 2. The test results from the core samples (no-rejuvenation) are presented in Fig. 2 as a black circle labeled "RAP". As expected, the amount of rutting for the non-rejuvenated material was minimal since the pavement appeared to be stiff and considerably aged.

Rut depth results showed an increase in rutting as the rejuvenator dosage was increased for all four rejuvenators, which agrees with literature [7]. A small change in dosage rate of the coal tar-based and petroleum distillated-based products tended to rejuvenate the RAP mix to a point where it rutted excessively compared to the two asphalt emulsion-based products.

Binder Stiffness Results and Selection of Optimum Rejuvenator Dosage Rates

The complex modulus ($G^*/\sin\delta$) at 82°F of the extracted binder taken from each APA test specimen can be seen in Fig. 3. As expected, the stiffness of the binder decreased with increasing rejuvenator content for all cases. To select the optimum dosage rate

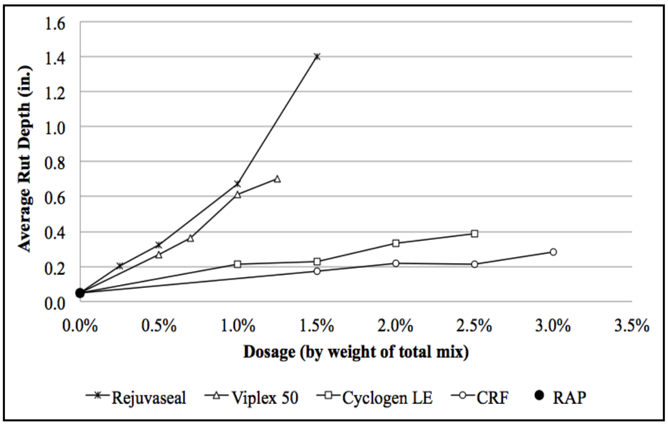


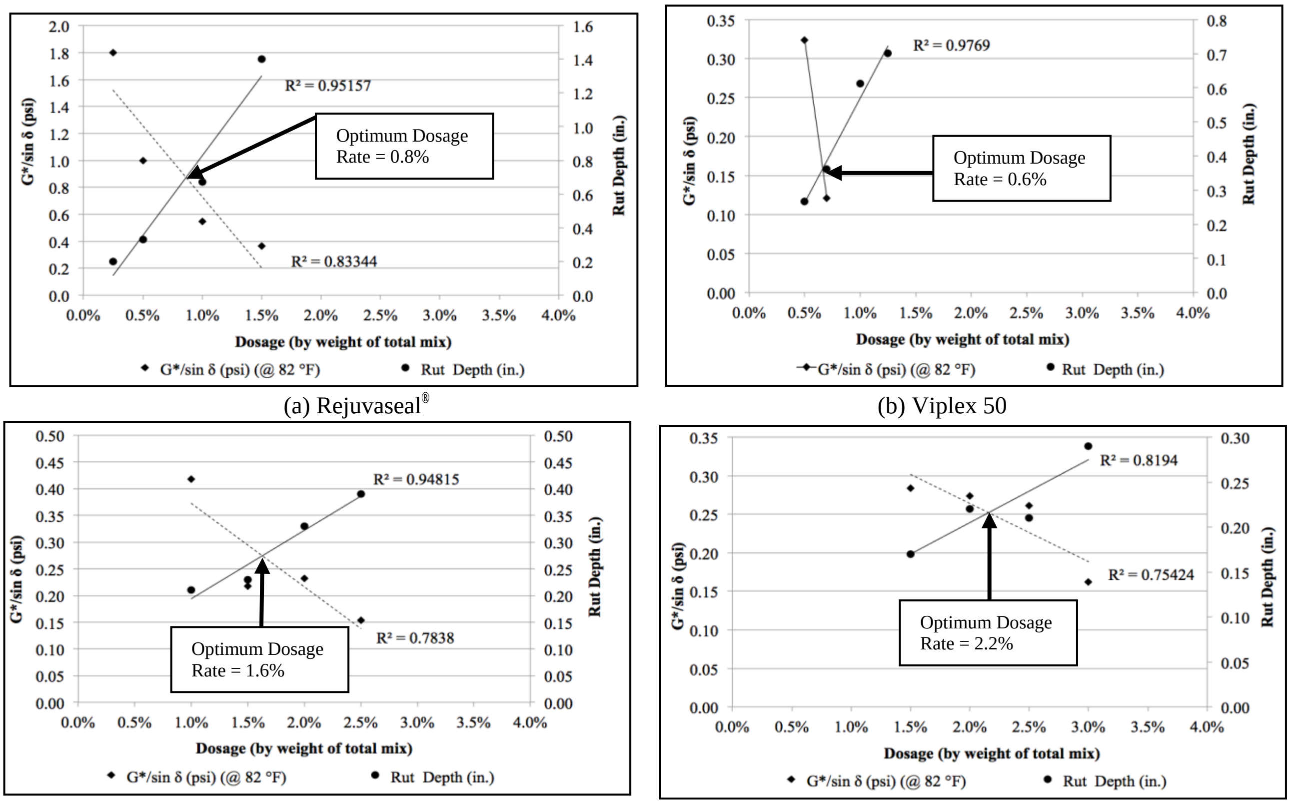
Fig. 2. Maximum Rut Depths for all Laboratory Mixes Tested.

to be used, the laboratory data were combined and analyzed to compare the performance of the recycled mixes in terms of rutting potential and binder stiffness. Both the rutting potential and binder stiffness results were linear with opposite slopes, which intersected at a point where the mixes were rejuvenated enough so that they did not show excessive rutting potential. The optimum dosage rates were determined by selecting the intersection of the plots for each parameter in Fig. 3 for each product and rounding down to the nearest half percent. The actual optimum dosage rate is shown in Fig. 3 for each rejuvenator. The optimum dosage rates selected for Rejuvaseal®, Viplex 50, Cyclogen LE®, and CRF® were 0.5, 0.5, 1.5, and 2.0, respectively. These results could be used as a starting point if any of these rejuvenators are used during HIR in remote locations where laboratory equipment is not available to determine optimum rejuvenator content. Since the specimens rejuvenated with 2.0% of CRF® proved to be the most rut resistant, this rejuvenator-dosage combination was selected to use for field trials.

Rejuvenator-Cement Combination Laboratory Test Results

The concept of adding Type I portland cement in combination with a rejuvenator to stiffen the asphalt mixture while still allowing for rejuvenation was explored in the laboratory before field trials. The APA was used to test three of the rejuvenators (Rejuvaseal®, Cyclogen LE®, and CRF®) at a cement content of 1.5% by total weight of the RAP mixture to determine if the addition of cement was able to decrease rutting potential for any of the three rejuvenators. The optimum dosage rates previously determined for each rejuvenator were used and the APA specimens were prepared as previously described.

Fig. 4 displays the APA maximum rut depths and the average air voids obtained for all rejuvenator-cement combinations. Cyclogen LE® and CRF® exhibited an increase in rutting potential due to the addition of cement. In contrast, Rejuvaseal®, a coal-tar based product, appeared to benefit from cement addition. Based on these results, further testing at additional cement contents was performed only with Rejuvaseal®. Since rut depth increased due to the addition of cement when Cyclogen LE® and CRF® were used, no additional testing was conducted with these rejuvenators and cement in combination. For Rejuvaseal®, at cement contents above 1%, maximum rut depth values appeared to be similar to the values observed at 1%. Since there appeared to be no considerable



(a) Rejuvaseal® (b) Viplex 50 (c) Cyclogen LE® (d) CRF®

Fig. 3. APA and DSR Data for Laboratory Rejuvenator Mixes.

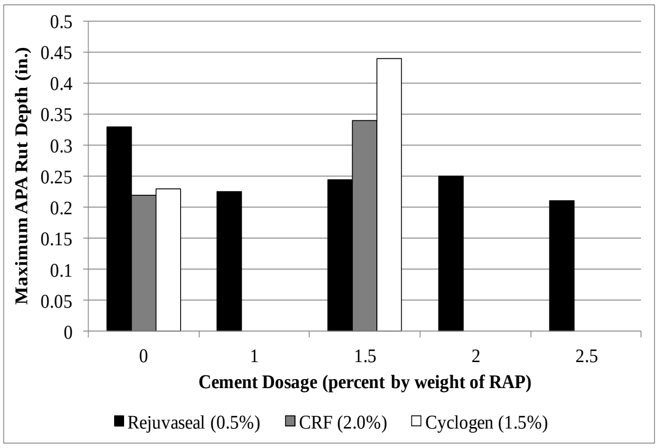


Fig. 4. APA Data for Cement-Rejuvenator Mixes.

advantage to be gained by adding additional cement, a cement content of 1% with 0.5% Rejuvaseal® was selected to use for field testing.

Field Evaluation

Description of Field Test Site

The test site used for the field testing portion of this study is an asphalt test section was constructed approximately four years prior to the field testing and was designed and constructed to support repeated loading by a C-17E Globemaster aircraft. The pavement structure consisted of 6 in. of asphalt and 8 in. of crushed limestone base (55 CBR) over two subbase layers. One subbase layer was a 6-in. stabilized clay-gravel layer (CBR 100), and the other subbase layer was a clay-gravel with a CBR of approximately 70. The compacted subgrade was a silt with a CBR of 40. This test site was chosen to evaluate the rutting performance of repairs under F-15E aircraft traffic since the material surrounding the repairs was capable of supporting the high loading and tire pressures of a simulated F-15E load.

The type and dosage rate of rejuvenator and the dosage rate of cement used for RAP-1 were determined from laboratory testing. Conversely, RAP-2 was used to simulate a situation where no prior laboratory testing had been performed other than general mix characterization. This scenario would likely be the case in a remote environment, and it was necessary to determine repair effectiveness and integrity using a RAP material for which optimum rejuvenator contents had not been determined. Four, 6-ft by 4-ft areas of the asphalt test section were excavated to a depth of approximately 6 in. The excavated test material was discarded since the intent was to use the two RAP materials as the asphalt layer of the repairs. The repairs were conducted on these excavations so that the depth of rejuvenated asphalt material was 6 in. The excavated repairs are shown in Fig. 5.

Repair Construction Methods

The following section describes the repair construction methods employed for the HIR field testing. Some construction details were omitted for brevity, but more detailed descriptions can be

Fig. 5. Excavated Field Repairs Prior to Asphalt Placement.

found in [13]. This RAP-1 and RAP-2 materials used for field testing were obtained by heating the pavement using an infrared heater (HeatwurxTM HWX-30S) and removing the softened material using a specialized device that attaches to a skid steer loader referred to as an asphalt processor (HeatwurxTM AP-30). The infrared heater is an electric infrared heater packaged with a generator that is powered by diesel fuel. The asphalt processor is a device similar to a tiller that breaks down the asphalt mass into a finer and more evenly distributed gradation without causing aggregate breakage that would result if a traditional milling head is used. After the asphalt processor was used, the material was removed from the existing pavement using a skid steer loader and stockpiled for later use. Typically a few larger chunks of material were discovered, which were discarded. It was determined that additional RAP material would be required to compensate the volume of material discarded and any volume changes due to differences in compaction level. In a remote environment it is suggested that this extra material be obtained from a less critical part of the airfield such as shoulder areas. It is important to note that the RAP obtained was not immediately rejuvenated, heated, placed, and compacted since the sites where RAP-1 and RAP-2 were obtained were not located adjacent to the asphalt test section where the full scale repairs were conducted.

The RAP material was weighed before rejuvenation using a plastic container and digital scale, and the weights were recorded to the nearest pound. To mix the rejuvenator with the RAP, a mixing drum and heater attachment for a skid steer loader was employed. A more detailed description of this device and additional information concerning field repairs can be found [13]. Approximately 350 lb of

RAP were placed into the drum at one time, and the appropriate amount of rejuvenator was added after the mixture had been reheated to 325°F. Approximately 1,650 lb of RAP material were needed for each 4-ft by 6-ft repair, requiring six mix batches for each repair. Accordingly, each rejuvenated drum load was placed into a stockpile adjacent to the repair area and the temperature was maintained using an infrared heater that was positioned above the stockpile. The target stockpile temperature selected was 350°F so that the material could be easily placed and compacted, but scorching of the rejuvenated material could be avoided. As discussed in the Specimen Preparation and Compaction section of this paper, the target laboratory mixing and compaction temperature was 140°F since it was expected that residual heat and the addition of a rejuvenator would soften the mixture enough to compact the recycled mixture and achieve the target density without additional heating. However, after preliminary testing, it was observed that the mixture required reheating to 350°F in order to achieve the target density. Furthermore, as discussed previously, RAP-1 and RAP-2 were obtained from different locations than the test section, so these materials would have required at least some reheating.

Before placement and compaction of the rejuvenated RAP, the base course of the excavation was compacted using a rammer-style compactor. The top of the base course was sprayed with an asphalt emulsion to act as a tack coat. The emulsion was also sprayed between lifts of rejuvenated RAP. All field repairs were constructed in this manner with some exceptions. Repair 1 was placed and compacted in one lift, but Repairs 2, 3, and 4 were placed and compacted in two lifts. Additionally, the rejuvenator and cement used for the second lift of Repair 4 were mixed in-place using the asphalt processor and an infrared heater was used to bring the RAP up to compaction temperature. This method was being investigated in other parts of the research and was chosen to be employed for Repair 4. After placement and leveling, each lift was compacted with a small, dual-wheel vibratory roller (Wacker Neuson RD12). A smaller roller was used based on equipment requirements provided by the sponsor. Repair densities were measured during compaction at three locations using a nuclear density gauge. The measurement readings were recorded as a single average density for the overall repair and used to evaluate the compaction effort. To establish a correlation between the nuclear gauge device and actual field densities, two core samples were taken and sent to the laboratory for density determination. Comparative testing revealed that the nuclear gauge results were on average 10 pcf lower than the core densities. Therefore, the compaction effort ceased when nuclear gauge readings were 135 pcf or higher since the minimum target density was 145 pcf. A more detailed description of the recycling and rejuvenation process can be found [13].

Simulated Aircraft Traffic and Data Collection

The repairs were trafficked using the F-15E load cart shown in Fig. 6. This load cart is equipped with a 36-in.-diam, 11-in.-wide, 18-ply tire inflated to 325 psi and loaded so that the single test wheel supported 35,235 lb. The load cart is powered by the front half of a U.S. Army 2.5-ton transport truck with an outrigger wheel to prevent overturning. The multiple-lane trafficking pattern illustrated in Fig. 6 was used. Trafficking consisted of driving the load cart forward and then backward over the repairs in the same wheel path, then moving 9 in. laterally to the adjacent path and repeating. The width of each wheel path was the approximate width of the traffic tire. One traverse of the repair width was defined as one coverage or 16 total passes. The objective number of passes for each of the repairs to sustain was 3,500. Pre-traffic measurements of rut depth were obtained with rod and level as well as straight edge and tape measure as a baseline in three separate cross sections (north, center and south of each repair). Failure criterion was considered to be 1-in. rut depth. Pavement temperatures were not collected during trafficking, but the surface temperature was the same for each repair since they were all trafficked simultaneously. Fig. 7 shows an example of one of the repairs at the conclusion of trafficking.

Trafficking Results and Discussion

The traffic data were collected at different intervals to capture the rutting behavior of the repairs as trafficking progressed. The repairs were trafficked to over 255 coverages (4,086 passes total), and none of the repairs experienced a rut depth of 1 in. or greater. Therefore, all full-scale repairs met the objective of 3,500 passes. Table 1 lists the rut depths measured for each of the repairs, and the rejuvenator/rejuvenator-cement combinations tested. It is noteworthy that the rut depth and in-place density had an inverse relationship. Repairs 1 and 2 showed that the rejuvenator and rejuvenator-cement combinations evaluated in the laboratory translated well to full scale repairs that can support considerable aircraft traffic. Repair 3 was RAP-2 rejuvenated with 2.0% CRF® and Repair 4 was not rejuvenated. The method of using HIR and the suggested rejuvenator content for an asphalt-emulsion based rejuvenator can be used when the properties of the RAP material are

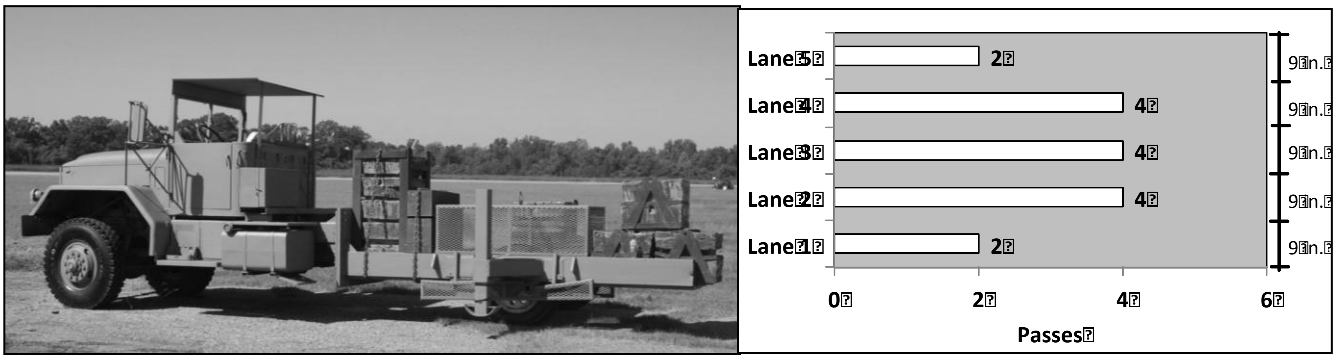


Fig. 6. F-15E Load Cart and Trafficking Layout.

Fig. 7. Example of Repair after Trafficking

Table 1. Rut Depth Data from Full Scale Trafficking.

Repair	Repair Description	In-Place Density (pcf)	Passes Of F-15E	Maximum Rut Depth (in.)
1	RAP-1 + 2% CRF®	140.3	4086	0.6
2	RAP-1 + 0.5% Rejuvaseal® + 1% cement	138.6	4086	0.9
3	RAP-2 + 2% CRF®	148.3	4086	0.3
4	RAP-2 (no rejuvenator)	144.8	4086	0.4

unknown. Also, an asphalt repair can be conducted without using rejuvenator if a localized structural failure such as a pothole or a depression is discovered on an airfield in an area that does not appear to be severely aged.

Binder Testing from Field Sampling

Core samples from Repairs 1 and 2 were obtained after trafficking and the binder was subjected to DSR testing to confirm the softening of RAP binder that was observed in laboratory testing. DSR testing was performed in accordance with AASHTO T 315. After the binder was extracted and recovered, DSR testing commenced on the original binder and after the binder specimens were PAV aged in order to evaluate the long term performance of the repair. Superpave performance grade binder specifications were used to analyze the DSR data (1.0 kPa minimum for original binder and 5,000 kPa max for PAV aged binder). Higher failure temperatures indicated stiffer binder. Fig. 8 shows the failure temperatures exhibited by the original RAP material binder (Original), RAP binder that had been heated for extraction, but not rejuvenated (No Rejuv.) and binder from core samples from Repairs 1 and 2. The data indicate that a stiffening of the RAP binder occurs during the heating process, and the addition of rejuvenator can slightly reduce binder stiffness. Also, the binder extracted from Repair 2 indicates that the addition of cement can cause a stiffening of the binder in excess of the original stiffness. While the binder stiffness exhibited after rejuvenation was higher than the original

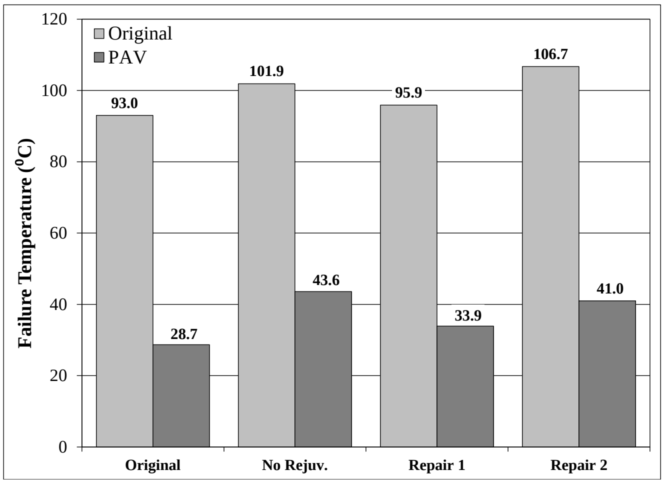


Fig. 8. DSR Failure Temperatures of Repair Samples.

RAP binder, it should be considered that the top two inches of the pavement from where the RAP-1 was obtained was highly oxidized as described in the experimental program section. The binder in this portion of the pavement was so stiff that DSR testing could not be performed. The results exhibited by Repairs 1 and 2 likely indicate that the addition of a rejuvenator could result in a repair surface that is much less oxidized and brittle than the original pavement surface layer.

Conclusions

This study explored the use of HIR techniques for conducting small repairs of aged AC on airfield pavements and the following conclusions were reached:

- The laboratory rutting performance of a recycled mix depends on the type of rejuvenator and the dosage rate used. CRF® (an asphalt emulsion-based rejuvenator) at a 2% dosage rate proved to be the best performing rejuvenator-dosage combination for the RAP material tested.
- Addition of Type I portland cement along with a rejuvenator produced mixed results in terms of laboratory rutting performance. Rutting resistance decreased when cement was used with asphalt emulsion-based rejuvenators, but increased rut resistance with a coal-tar based rejuvenator at a cement dosage rate of 1%.
- The optimum rejuvenator type and dosage rate determined from laboratory testing performed well in field trails. The 6-ft by 4-ft repairs were able to withstand the objective of 3,500 passes of F-15E aircraft traffic.
- The airfield repair that employed a coal tar-based rejuvenator at a dosage rate of 0.5% with 1% cement sustained the objective amount of aircraft traffic, but did not appear to improve rut resistance compared to using only an asphalt emulsion-based rejuvenator.
- The best performing rejuvenator-dosage rate combination from laboratory testing was also used in a full scale repair for a RAP material for which only general mix characterization properties were known. This repair also withstood the required amount of aircraft traffic.
- Using a rejuvenator during HIR of aged AC airfield pavements

appears to soften aged RAP binder somewhat, which could result in a repair surface that is much less oxidized and brittle than the original pavement surface layer.

Recommendations

If laboratory equipment is available, it is recommended to determine the optimum rejuvenator content for RAP material based on rutting potential and rejuvenated binder stiffness. If laboratory equipment is not available, it is recommended to use the optimum rejuvenator contents developed in this paper for the different types of rejuvenators investigated as a starting point and adjust as necessary. In addition, asphalt emulsion-based rejuvenators are recommended over other rejuvenator types based on the laboratory testing conducted. Using Type I cement is not recommended for use based on the field results obtained, but could stiffen rejuvenated RAP binder when used in combination with a coal-tar based rejuvenator. Users of coal tar based rejuvenators should consult the latest research on the possibility of these rejuvenators being carcinogenic before use. Use of HIR is recommended for performing small repairs of aged AC on airfield pavements in remote areas where quality asphalt materials are difficult to obtain. An asphalt emulsion-based rejuvenator is recommended for use in the HIR process in order to produce a longer lasting repair.

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