University of Illinois at Urbana-Champaign
Illinois Center for Transportation
Rantoul, IL

IAPA Finkbiner Memorial Scholarship Report

"Durability Enhancement of Asphalt Concrete by Utilizing Rejuvenators"

Prepared for the IAPA Scholarship Board
By: Arturo F. Espinoza-Luque

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Disclaimer

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of ICT. This paper does not constitute a standard, specification, or regulation.

1. INTRODUCTION

The national road network, is a crucial component of the transportation infrastructure, as it plays a pivotal role in promoting economic growth, and connecting communities across the country. However, shrinking budgets, increasing user demand, higher construction and maintenance costs, and a complex political landscape, have increased the strain on an already aging road network in the USA. Proof of this is that the American Society of Civil Engineers (ASCE) 2017 Infrastructure Report Card, rates the USA road network as 'D' which translates into a 'Poor/at Risk' condition [1]. This translates into more frequent and more prolonged congestions, which increases the man-hour lost by American workers, estimated at 42 hours per driver per year. Increasing congestion also leads to higher freight transportation costs, which depreciates the cost of goods, for the USA it is estimated that by 2030 increase congestion could mean a 44% increase in the cost of doing business [2]. Finally, road congestion also increases fuel consumption, and raises the concentration of air pollutants in high traffic areas, negatively affecting public health [3].

Under this context, it is evident that ensuring an adequate level of serviceability for the nation's roads is of interest to government agencies and users. Limited funding, however, is always a potential challenge that transportation professionals encounter when devising plans for road construction, preservation, and rehabilitation. This highlights the importance of improving the durability of pavements; the more our roads can last without needing repair, the less funding they will require during its service life, and more resources could be available for improving other sections of the network. To achieve better road durability, researchers have focused their efforts on addressing two of the most common type of distresses that affect asphalt concrete (AC) pavements: cracking and permanent deformation.

Permanent deformation, or rutting, is associated with the formation of a channel type depression along the wheel path. This type of distress reduces the pavement serviceability and creates potentially hazardous hydroplaning conditions [4]. Rutting can be the result of AC densification (consolidation), plastic or shear deformation; or a combination of both [5]. Major factors affecting permanent deformation are the pavement structure (layer thicknesses and quality), traffic volume, initial field compaction, and environmental effects such as moisture and temperature [6].

Cracking occurs when there is a separation of pavement particles; it is a primary mode of distress on pavements, and widespread cracking presence is usually a trigger for pavement maintenance or rehabilitation [7]. There are different types of cracks that form on AC pavements each with their own initiation mechanisms; the four major modes are thermal, reflection, fatigue, and top-down [4,8–10].

Major factors influencing the durability of AC pavements are the age hardening that asphalt undergoes while in service, and the increasing amount of recycled asphalt materials such reclaimed asphalt pavement (RAP), and recycled asphalt shingles (RAS), which adds a considerable amount of age-hardened asphalt to new AC mixes. Although the primary motivations to include recycled materials on AC is economical, asphalt being the most costly component of AC, or environmental, reduce the amount of virgin material demand; research has acknowledged that the incorporation of age-hardened materials increases the stiffness and brittleness of AC [11–15]. To counterbalance the detrimental effects of age-hardened asphalt, it is common practice to use rejuvenators.

The interaction dynamics between rejuvenators and recycled asphalt binder have mostly been studied at a binder level [16–19]. This method permits the understanding of how much the recycling agents can improve the condition of aged asphalt binder; however, in practice the rejuvenators are used directly into AC mixes, by combining it with RAP material at the mixing plant [20], as surface treatment [21], or as an additive while performing in-place recycling [22]. Therefore, understanding the impact of rejuvenation at mix level is a research area that has attracted research attention [23,24].

2. RESEARCH OBJECTIVE

The primary objective of this study is to assess the capacity of rejuvenators to improve AC performance in terms of rutting, and cracking potential, using Hamburg Wheel Track Test (HWTT) and the Illinois Flexibility Index Test (I-FIT), respectively. Additionally, this study also looks into the effect of short-term aging (STA) on rejuvenated AC mix blends.

3. MATERIALS AND EXPERIMENTAL PROGRAM

This study was conducted using one dense-graded AC mix and one type of rejuvenator. The mix is a Superpave design commonly used for low to mid-volume roads by Illinois contractors. The rejuvenator is an aromatic oil, which is readily available in the market.

3.1 Mix Design

The AC mix used in this study was designed following Superpave design method, using 50 gyrations and a nominal maximum aggregate size (NMAS) of 9.5mm. The binder type and content are PG 64-22 and 5.9%, respectively. RAP content is 15%. In this report, the mix is identified as “N50”.

3.2 Rejuvenator Characteristics

The rejuvenator employed in this study is a paraffinic distillate solvent extract with the appearance and viscosity of a dark brown lubricating oil. Chemically, it is composing of different hydrocarbons; with aromatic hydrocarbons being the primary component (>75%). The product is readily available in the market, and its formula is proprietary.

3.3 Specimen Preparation

All tests were performed on Plant Mix Lab Compacted (PMLC) specimens. The air void target range for the specimens was 7.0% ± 0.5%. For this study, three different blends of mix-rejuvenator were prepared by adding 3%, 6%, and 9% of rejuvenator, by weight of binder content. The required dosage was directly poured into a batch of hot loose mix material and stirred using a mechanical mixer. To evaluate the effect of STA, after the required dosage of rejuvenator was added, the mix was subjected to a 2-hour conditioning cycle on a forced draft oven at a temperature of 135°C ± 3°C, as specified by AASHTO method R30 [25]. The test results of the different blends were compared to a control blend, which contained no rejuvenator.

3.4 Illinois Flexibility Index Test (I-FIT)

The I-FIT procedure follows AASHTO TP124 protocol [26], with the goal of obtaining the load-displacement curve generated from loading a semi-circular specimen with a monotonic displacement rate of 50mm/min. Table 1 shows the test parameters and Fig. 1 presents the main outputs from the test. A Flexibility Index (FI) can be obtained using Equation 1. In general, higher values of FI indicate higher resistance to crack propagation:

$$FI = A * \frac{G_f}{abs(m)} \tag{1}$$

where FI is the flexibility index; G_f is the fracture energy, defined as the area under the load-displacement curve, J/m^2; m is the slope of the tangent obtained at the inflection point of the post-peak curve, kN/mm; and A is a unit conversion and scaling coefficient taken as 0.01.

Table 1 Specimen and test parameters for I-FIT test

I-FIT Parameters	
Specimen Thickness (mm)	50 ± 1
Specimen Diameter (mm)	150 ± 1
Notch Length (mm)	15 ± 1
Notch Width (mm)	1.5 ± 0.05
Loading Rate (mm/min)	50
Test Temperature (°C)	25

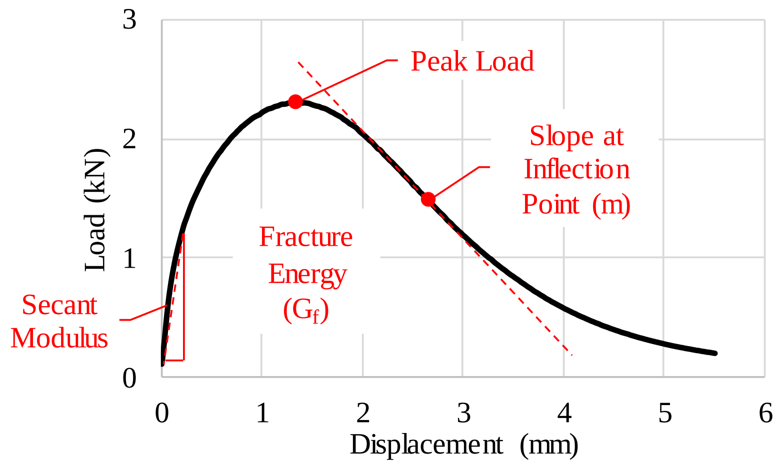

Fig. 1 Typical outcome from I-FIT test, after Ozer et al. [15]

3.5 Hamburg Wheel Track Test (HWTT)

Hamburg Wheel Track Test is a standard test used to evaluate the permanent deformation susceptibility of AC mixes; standard procedure follows AASHTO specification T324 [27]. Two pairs of AC samples of 150mm diameter and 62mm thickness are subjected to a cyclical loading from a rolling-wheel device while keeping the specimens submerged in a 50°C water bath. The objective of the test is to measure the rutting depression (in mm) formed on the specimens after a predefined number of cycles or to record the number of cycles that were necessary to achieve a maximum allowed depression level. Lower depression measurements, or the higher number of cycles, are indicators that the mix is more rutting resistant.

4. RESULTS AND DISCUSSION

4.1 I-FIT Performance

Table 2 summarizes the main results from the I-FIT test along with their respective Coefficients of Variation (CoV). Regarding peak load values, the effect of rejuvenating is evident, with increasing dosage the load values decrease, and with STA conditioning the values increase with respect to their corresponding UA values. For fracture energy, there is no consistent trend with increasing dosage; the values go up from 0% to 3% but then experience an overall decrease in both UA and STA conditions. Also, the effect is not evident between the two specimen conditions, from 0% to 6% STA specimens show lower fracture energy than the UA specimens, however, at 9% this trend is reversed. This indicates that fracture energy alone may not be a suitable parameter to differentiate between AC mixes as has been shown by previous research [13,15]. The secant modulus value indicates the stiffness of the material before crack propagation. For this study, secant modulus is obtained as the ratio between 50% of peak load and the displacement at that point. Secant modulus followed the same trend as the peak loads.

Table 2 Output from I-FIT test

		Average					COV [%]				
Blend	**Condition**	**Peak Load [kN]**	**Fracture Energy [J/m2]**	**Secant Modulus [kN/mm]**	**Slope**	**FI**	**Peak Load**	**Fracture Energy**	**Secant Modulus**	**Slope**	**FI**
0% Rej. (Control)	**UA**	4.27	1602	9.37	5.56	3.0	4.6	9.7	13.0	15.0	20.3
	STA	4.32	1558	9.49	5.59	2.9	4.4	5.9	15.9	17.9	18.9
3% Rej.	**UA**	3.20	1838	6.12	2.42	7.9	7.3	7.2	22.0	19.5	20.6
	STA	3.30	1710	6.67	2.89	6.0	5.8	6.7	15.0	12.2	16.4
6% Rej.	**UA**	2.53	1701	4.60	1.78	9.9	10.9	14.3	11.4	15.7	25.3
	STA	2.59	1586	4.69	2.00	8.4	13.2	9.7	18.9	23.2	30.7
9% Rej.	**UA**	1.99	1389	3.50	1.17	12.0	6.4	8.9	10.6	13.4	13.8
	STA	2.34	1593	3.90	1.65	10.7	17.5	13.7	25.3	41.8	30.8

For the slope, higher absolute values indicate an AC mix that experiences faster crack propagation, while lower values are related to slower crack propagation. Table 2 shows that with increasing rejuvenator application there is a reduction in slope values, with the steepest decline being between 0% and 3%. Regarding the effect of STA, there is an increase in slope values, which should be expected with as aging increase; with the highest relative difference between stages presented on the specimens with 9% rejuvenator, with a difference between condition stages close to 42%.

For FI, there is an overall trend of increase in FI with higher rejuvenator dosages, clearly shown in Fig. 2. This reflects the effectiveness of using a rejuvenator to improve the cracking resistance, of the AC mix. The highest jump in FI is experienced between 0% and 3% specimens, and as higher dosages are used, the FI improvement becomes of less relative impact, suggesting that there will be only so much rejuvenator that will improve cracking resistance. Although the CoV for FI is greater than fracture energy, the ability of FI to discriminate the effect of the rejuvenator content and aging is evident.

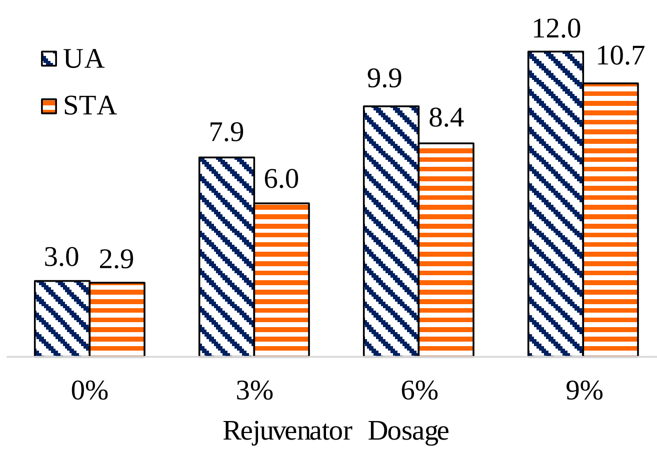

Fig. 2 FI Results, by dosage and conditioning type.

4.2 *HWTT Performance*

In Illinois, the pass/fail criteria for rut depth for a mix prepared with a 64-22 binder grade is compared at 7,500 passes against the maximum allowed threshold of 12.5 mm. In this study, at 7,500 passes all samples, aged and un-aged, were below 12.5 mm; thus, a comparison of final rut depth was performed at 10,000 passes since the rut progression data is already available for all blends, and at this point, the effect of any stripping will be more evident. Fig. 3 presents the rut depth at 10,000 passes for all AC blend types. The plot shows a direct relationship between increasing dosage and rut depth; with a significant increase when 9% rejuvenator was added. On the other hand, STA samples show a much smaller increment between the different concentration levels. It should be expected that adding rejuvenator to the AC mix would reduce its permanent deformation resistance since the rejuvenator softens the asphalt binder in the mix. However, STA conditioning could reduce the potential rutting as would be expected regardless of the rejuvenator ration.

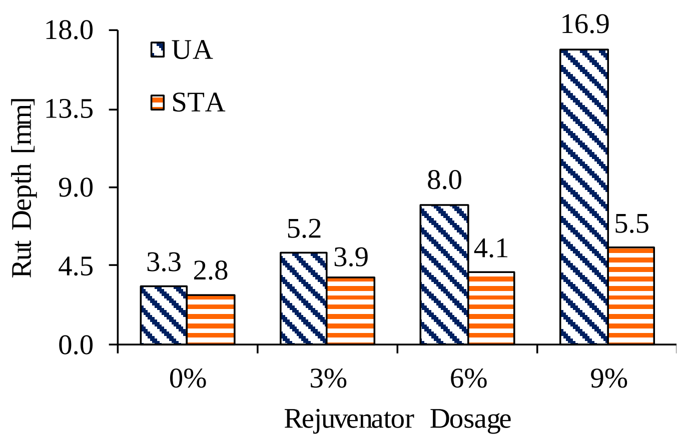

Fig. 3 Final rut depth at 10,000 passes, all blends.

4.3 Balance Mix Design Analysis

The Illinois Center for Transportation (ICT) at the University of Illinois at Urbana–Champaign has applied the concept of Illinois Balanced Mix Design (I-BMD) to improve the screening of high and low-performance AC mixes [15,28,29]. Their approach consists of analyzing interaction plots between FI, secant modulus from I-FIT, and rut depth. This approach involves combining the results from I-FIT and HWTT results in a plot divided into four quadrants while values are checked against secant modulus threshold:

- QI. Stiff and flexible: mixes with adequate cracking (flexible) and rutting (stiff) resistance.
- QII. Soft and flexible: mixes with good crack resistant (flexible) but high rutting potential (soft).
- QIII. Stiff and brittle: low rutting potential (stiff) but prone to cracking (brittle).
- QIV. Soft and unstable: low cracking and rutting resistance.

The secant modulus was selected to be between 2 and 10 kN/mm (11.4 to 57.2 kip/in). In this case, all tests were within the selected thresholds. For FI, a minimum of 8 was considered acceptable; while the maximum acceptable rut depth is 12.5 mm at 10,000 passes. The quadrants' definitions and thresholds are based on previous work carried at ICT [13–15,28,29]. It is important to notice that threshold levels should be adjusted for local materials and conditions.

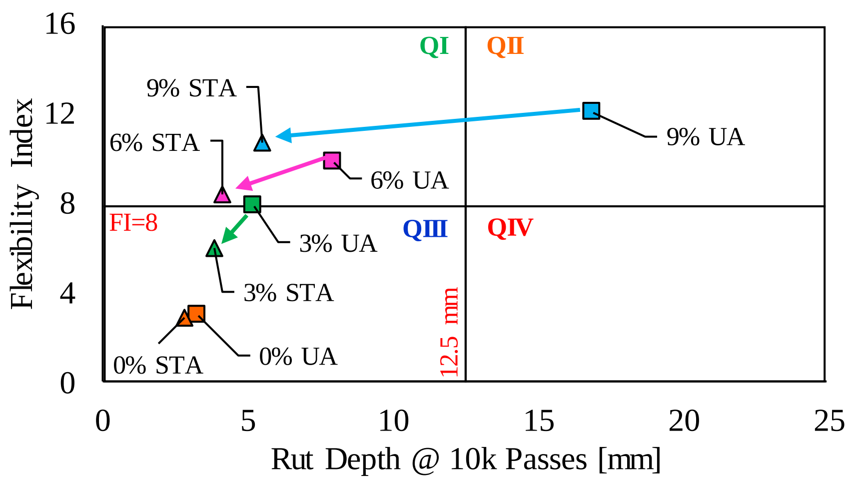

Fig. 4 2D Interaction plot between rut depth and FI

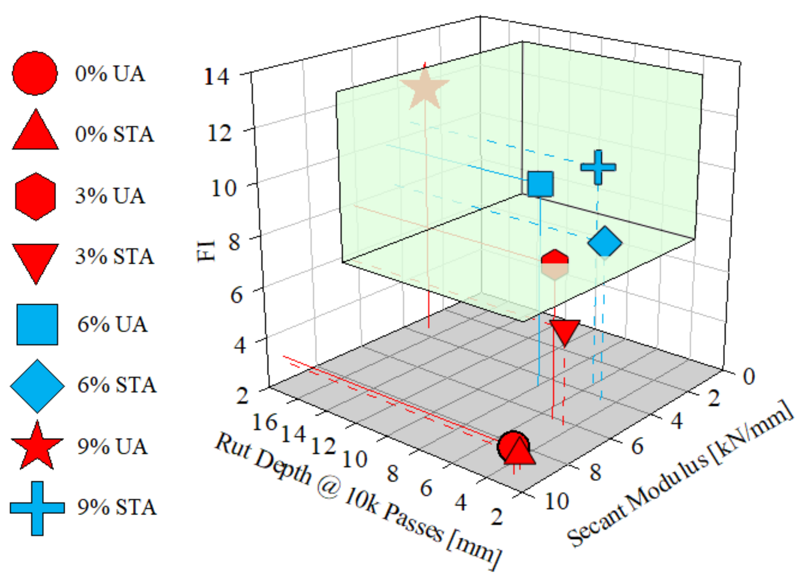

Fig. 5 3D Interaction plot between rut depth, FI, and secant modulus

Fig. 4 presents the 2D I-BMD plot for all AC mixes in this study and Fig. 5 shows the expanded 3D I-BMD plot integrating secant modulus, in this figure, a red color icon indicates failed FI and/or rutting, yellow color icon indicates passing FI and rutting but with a secant modulus value outside the range; a blue color indicates compliance with all three criteria, which are represented by the light-green shaded borders. As the rejuvenator dosage increases, the AC mix becomes more flexible, it achieves higher FI values, and the secant modulus is lowered; but at 9% it becomes the gain in flexibility is shadowed by the severe softening of the material, experiencing high rutting. Aging showed that it reduces the potential for rutting and flexibility while having a minimal effect on secant modulus. At 9% dosage, the STA samples show a reduced amount of deformation compared to the UA samples. This highlights how adding rejuvenator to an AC mix could improve its durability in terms of cracking resistance, without suffering a significant reduction in rutting resistance, especially if the aging conditioning is considered. From these results, it appears that 6% rejuvenator dosage might be the most adequate since at both UA and STA conditions the specimens fall within the most desirable quadrant QI, and still maintains adequate stiffness values.

5. CONCLUSION

This study presents a practical application of using the Illinois Flexibility Index Test as a tool to assess the flexibility properties of AC materials that have been combined with different dosages of rejuvenator, and subjective to different conditioning methods. In combination with the Hamburg Wheel Track Test, a 2D and 3D I-BMD analysis shows that adding rejuvenators to AC does improve its flexibility. However, its effect becomes less significant as the dosage is increased. Also, the softening effect of the rejuvenator is evident, and its impact continues to grow with higher dosages, especially under UA conditions. The opposite effect that rejuvenation has on AC cracking and rutting resistance highlight the importance of incorporating a BMD analysis to mix performance criteria. For this type of mix and testing conditions, 6% rejuvenator by weight of the binder content, appears to be the optimal dosage in terms of acceptable FI and rut depth, and without experiencing excessive behavior changes between UA and STA conditions.

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